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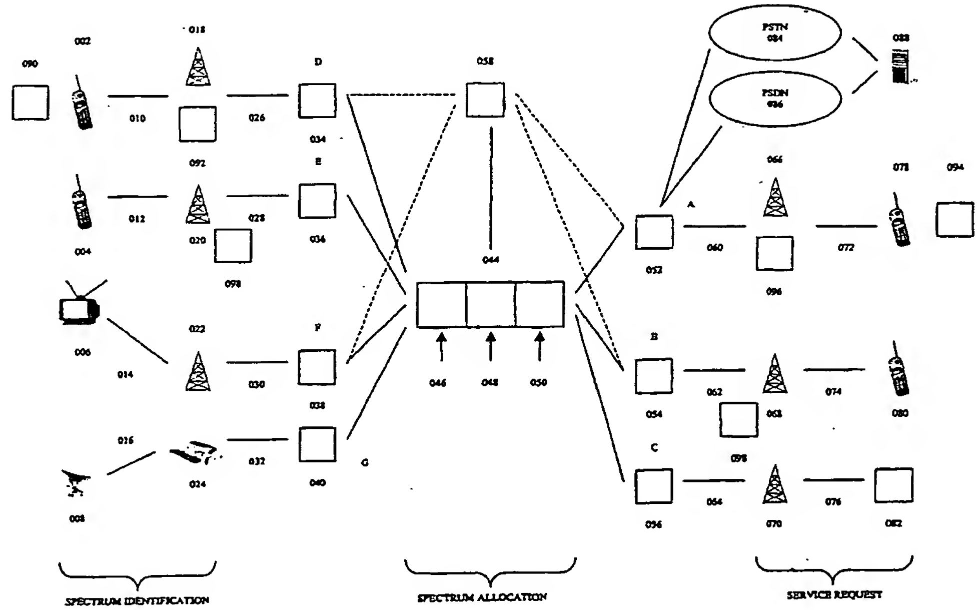


(57) Abstract: A system and method for dynamic utilization of all available spectrum (Fig. 1) obtains service requests from communication stations such as a wireless unit (004). The system takes the request in a real time, and in advance, identifies underutilized spectrum to match the uderutilized spectrum to the service request. In addition the system is a signaling system that interconnects different wireless networks to enable them to exchange information.

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# SYSTEM AND METHOD AND APPARATUS FOR ENABLING DYNAMIC UTILIZATION OF ALL AVAILABLE SPECTRUM AND DYNAMIC ALLOCATION OF SPECTRUM

## RELATED APPLICATION

The present application relates back to the provisional application, Serial Number 60/232,033, filed September 12, 2000 entitled "METHODS AND APPARATUS ENABLING THE DYNAMIC UTILIZATION OF ALL AVAILABLE SPECTRUM AND THE EFFICIENT ALLOCATION OF SPECTRUM TO THE MOST HIGHLY VALUED COMMUNICATIONS SERVICES," and incorporated herein by reference.

## FIELD OF THE INVENTION

The present invention generally relates to wireless communications systems. More particularly, the present invention relates to novel and improved systems and methods for utilizing radio spectrum more efficiently by: (1) dynamically identifying and utilizing any and all underutilized spectrum; and (2) dynamically allocating spectrum to the most highly valued communications services.

## BACKGROUND

Almost all types of wireless services may need additional capacity at any given time. The present invention defines wireless networks wishing to operate in underutilized spectrum as Service Demand Entities (SDE) (see DEFINITION Section for a more complete definition) and wireless networks with underutilized spectrum as Spectrum Supply Entities (SSE) (see DEFINITIONS Section for a more complete definition).

In recent years, most operators of Commercial Mobile Radio Service (CMRS) have experienced demand for wireless service that exceeds available supply, particularly during peak times and in urban areas. However, operators of other wireless services have also experienced periods when demand for their service exceeds available supply. For example, the public safety organizations often experience times when their networks become congested.

In addition, operators of many wireless services want greater access to spectrum on a long-term basis. In the U.S., the regulatory body responsible for licensing spectrum is the Federal Communications Commission (FCC), which faces requests for licenses to operate in spectrum that significantly exceeds the available supply of spectrum.

At the same time some operators of wireless services face demand that exceeds supply, other wireless operators may not fully utilize the spectrum in which they are licensed to operate.

**OBJECTS OF THE INVENTION**

The present invention includes the following objectives:

1. Expand capacity of wireless networks. The present invention aims to enable all wireless networks, in general, and mobile networks, in particular, to transmit and receive more traffic than they would in the absence of the invention.

2. Increase the speed of transmission. The present invention aims to enable all wireless networks, in general, and mobile networks, in particular, to transmit traffic faster than they would in the absence of the invention.

3. Enable wireless networks to provide differentiated services. The present invention aims to enable all wireless networks, in general, and mobile networks, in particular, to treat different traffic differently and allocate traffic to the channel resource best suited for its transmission.

4. Minimize interference with Incumbent Licensees. The present invention aims to ensure that any additional traffic transmitted over the channel resource of Incumbent Licensees does not cause undue interference with the transmissions of Incumbent Licensees.

5. Minimize total cost. The present invention aims to minimize the total cost of implementing the methods and apparatus. The total costs should be less than the value that customers would place on the incremental amount of available channel resources enabled by the invention.

6. Utilize existing and projected infrastructure as much as possible. The present invention aims to utilize existing hardware, software, and protocols deployed by Incumbent Licensees and Wireless Operators requesting channel resources.

## SUMMARY OF THE INVENTION

The present invention describes a general approach of utilizing underutilized spectrum more efficiently than under existing approaches. The approach involves the SDE and the station subscribing to the wireless service provided by the SDE (Service Demand Station or SDS) transmitting and receiving signals to and from each other over a carrier frequency of the underutilized spectrum.

To enable the general approach of utilizing underutilized spectrum, the present invention includes systems, methods, and apparatus that individually and collectively:

1. Obtain requests for service, both in real-time and in advance.

2. Identify underutilized spectrum, both in real-time and in advance.

3. Match underutilized spectrum to service requests.

4. Transmit relevant information about such allocations to the SDE to enable the SDE and SDS to operate in the underutilized spectrum.

5. Ensure that the exchange of signals between the SDE and SDS do not cause undue interference with the signals exchanged between the SSE and its own stations.

The present invention applies to all wireless operators requesting service and identification of underutilized spectrum of all wireless operators. That is, the present invention enables any wireless operator needing additional spectrum to request spectrum. These operators include without limitation: CMRS operators like Verizon Wireless, television broadcast operators, either digital or analog, and satellite operators, either fixed or wireless.

DEFINITIONS

*Azimuth.* The angle between a reference point and some remote point that lies in the plane tangent to the earth that contains both points.

*Azimuthal.* Of or relating to or in azimuth.

*Brokers.* An entity other than a Spectrum Supply Entity (SSE) or Service Demand Entity (SDE) that purchases, offers to purchase, sells, or offers to sell channel resources.

*Channel Resource.* A set comprising certain frequency, time, code, space, and polarization resources that can be used to enable a communications channel between two nodes or stations within a wireless network.

*Code Resource.* Channel coding and modulation techniques that enable multiple messages to be transmitted simultaneously in time using a shared communication channel.

*Elevation.* The angle between a reference point and some remote point that lies in the plane perpendicular to the earth that contains both points; of or relating to or in elevation.

*Ellipticity.* The ratio of the length of the semi-major axis to that of the semi-major axis of an ellipse. In the context of polarization, ellipticity is computed from the trajectory of the electric field vector after rotating into a coordinate system with zero tilt (see below).

*Fractional Allocation.* A method of channel resource allocation which allocates underutilized spectrum from some SDE's network, some other wireless network, and/or some combination of all wireless networks in response to some, but not all, service demand from the SDE.

*Frequency Resource.* A radio frequency band that can be used to enable a communications channel between two nodes within a wireless network.

*Gateway.* A node within a communications network equipped for interfacing with another network that uses different protocols.

*Headers.* Layer Control Information that is prepended to data that has been passed down from upper Open System Interconnection (OSI) layers.

*Incumbent Licensee.* The wireless operator holding the original license to operate in any given spectrum.

*Information Unit.* All Layer Control Information and data that has been passed down from an upper OSI layer.

*Layer Control Information.* Specific requests and instructions that are exchanged between peer OSI layers.

*Layer Service Provider.* An OSI protocol layer that provides services to Layer Service Users.

*Layer Service User.* An OSI protocol layer that requests services from an adjacent OSI layer.

*Leading Demand Indicator.* Any event or information that provides some indication of the timing and/or amount of spectrum an Incumbent Licensee will utilize in the future.

*Methods.* Procedures within object-oriented software.

*Object-Oriented.* An attribute of software that contains a collection of related procedures and data. Procedures within object-oriented software are often referred to as *methods*. Data within object-oriented software are often referred to as *variables*.

*Polarization Resource.* A particular electromagnetic wave polarization state that may be employed by a station within a wireless network to enable a communications channel with another station within the same network. Polarization states may be defined in terms of the relative amplitudes and phases of each of two orthogonal components; by polarization state tilt and ellipticity; by a Poincaré sphere representation; or by means of any other equivalent representation.

*Poincaré Sphere.* A representation of the possible polarization states of an electromagnetic wave. Each point on the Poincaré sphere maps to a unique polarization tilt and ellipticity.

*Protected Coverage Area.* A geographical area within which a station of some Incumbent Licensee is legally permitted to operate without undue interference from other stations. Regulations generally define protected coverage areas in terms of some minimum signal level received from the Incumbent Licensee's station along with a minimum acceptable desired-to-undersired signal ratio that must be respected within the coverage area.

*Poynting Power Density.* The power density in watts per square meter or equivalent units present in a propagating electromagnetic wave.

*Request for Service (RFS).* A request by a wireless operator for access to spectrum subject to the following factors, including without limitation: (a) time constraints; (b) cost constraints; (c) space constraints; (d) performance requirements; and (e) flow metrics.

*Service.* A set of requirements associated with transport of traffic over a network, including without limitation: time during which traffic must be transported; network performance level which must be supported while traffic is being transported; amount of traffic to be transported; and reliability with which traffic must be transported.

*Service Access Point (SAP).* A conceptual location at which one OSI layer can request the services of another OSI layer.

*Sharing Operator.* The wireless operator wishing to operate in the same spectrum as an Incumbent Licensee.

*Space Resource.* A channel resource defined in terms of the relation between geographical area of interest and the power density of signals being transported within a particular channel. Because wired networks employ guided transmission media, signals from one transmitting node can be transported to one or more intended receiving nodes in the network in such a way that the signal energy reaching other unintended receiving nodes is negligible. In wireless networks, the transmission medium is not guided. Therefore, the signal energy reaching unintended receiving nodes can be significant. Since a specific confined route cannot be chosen to minimize signal energy at unintended receivers, wireless networks employ transmitter output power and receiver and transmitter antenna gains to manage the sharing of space resources within a wireless network.

*Spectrum Demand Entity (SDE).* An entity that commits to buy underutilized spectrum. The entity could be: (1) a wireless service provider that operates its own network; (2) a wireless service provider that resells the services of other wireless service providers that operate their own network; (3) a third party acting as a broker between such operators and the Allocator and/or SSEs; (4) a party that commits to buy underutilized spectrum for speculative purposes; or (5) any other party committing to buy underutilized spectrum.

*Spectrum Supply Entity (SSE).* An entity that commits to provide any wireless operator access to underutilized spectrum. The entity could be: (1) an Incumbent Licensee that does not fully utilize all resources in its spectrum; (2) a wireless service provider that resells the services of other wireless service providers that operate their own network; (3) a third party acting as a broker between Incumbent Licensees and the Allocator and/or SDEs; (4) a party that commits to supply underutilized spectrum for speculative purposes; or (5) any other party committing to provide any wireless operator access to underutilized spectrum.

*Stations.* Any device that either transmits signals to and/or receives signals from a wireless network. Such devices can be either fixed or mobile.

*Tilt.* The angle through which a given coordinate system must be rotated so that the two orthogonal components of an electric field lie along the semi-major and semi-minor axes of an ellipse, where the component with lesser magnitude (including zero) lies along the semi-minor axis.

*Time Resource.* The time interval corresponding to the availability of frequency, code, space, and polarization resources within a communications channel.

*Trailers.* Layer Control Information that is appended to data that has been passed down from upper OSI layers.

*Total Allocation.* A method of channel resource allocation which allocates underutilized spectrum from some SDE's network, some other wireless network, and/or some combination of all wireless networks in response to all service demand from the SDE.

*Underutilized Spectrum.* Spectrum that serves as the frequency resource for any given Incumbent Licensee's channel for which sufficient time, code, space, or polarization resources exist such that another wireless operator could also use the same frequency resource to enable other channels on separate networks. In order for another wireless operator to use the same frequency resource owned by an Incumbent Licensee, the Sharing Operator must utilize a communications channel employing distinct time, code, space, and/or polarization resources.

*Unprotected Coverage Area.* Area outside of the protected coverage area of a station of some Incumbent Licensee.

*Variables.* Data within object-oriented software.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of System A-1 in accordance with one embodiment of the present invention.

Figure 2 is a flow chart illustrating the process for implementing System A-1 in accordance with another embodiment of the present invention.

Figure 3 is a block diagram of Apparatus A-3 in accordance with one embodiment of Method A-2.

Figure 4 is a block diagram illustrating the preferred embodiment of Method B-1 in accordance with one embodiment of the present invention.

Figure 5 is a flow chart illustrating the process for implementing Method B-1 in accordance with one embodiment of the present invention.

Figure 6 is a diagram illustrating how the present invention would implement Method C-2 in a particular geographical framework in accordance with one embodiment of the present invention.

Figure 7 is a block diagram illustrating the preferred embodiment of Method C-1 in accordance with one embodiment of the present invention.

Figure 8 is a flow chart illustrating the process for implementing Method C-1 in accordance with one embodiment of the present invention.

Figures 9 and 10 are diagrams illustrating a portion of the preferred embodiment of Method C-2 in accordance with one embodiment of the present invention.

Figures 11 and 12 are flow charts illustrating the process for implementing Method C-2 in accordance with one embodiment of the present invention.

Figure 13 is a diagram illustrating the preferred embodiment of Method C-3 in accordance with one embodiment of the present invention.

Figure 14 is a diagram illustrating the preferred embodiment of Method C-4 in accordance with one embodiment of the present invention.

Figure 15 is a block diagram illustrating the preferred embodiment of Method A-2 in accordance with one embodiment of the present invention.

Figure 16 is a flow chart, illustrating the process for implementing Method A-2 in accordance with one embodiment of the present invention.

Figure 17 is a diagram illustrating one example of an embodiment of Method D-1 in accordance with one embodiment of the present invention.

Figure 18 is a block diagram illustrating the preferred embodiment of Method D-2 in accordance with one embodiment of the present invention.

Figure 19 is a flow chart, illustrating the process for implementing Method D-2 in accordance with one embodiment of the present invention.

Figures 20-21 are diagrams illustrating the preferred embodiment of Method C-6 in accordance with one embodiment of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention includes the following overall systems, methods, and apparatus:

A.1. Overall System. An overall system of obtaining service requests, identifying underutilized spectrum, and matching underutilized spectrum to service requests.

A.2. Overall Method. An overall method of obtaining service requests, identifying underutilized spectrum, and matching underutilized spectrum to service requests.

A.3. Overall Apparatus. An overall apparatus that performs the functions of obtaining service requests, identifying underutilized spectrum, and matching underutilized spectrum to service requests.

A.4. Inter-Wireless Network Signaling System (IWNSS). A system of interconnecting different wireless networks to enable them to exchange information among each other.

A.1. Overall System

The present invention includes an overall system of enabling entities requesting service to operate in any underutilized spectrum.

**SYSTEM A-1:** *Overall System of Enabling Entities Requesting Service to Operate in Underutilized Spectrum.*

System A-1 as illustrated in Figs. 1 and 3, is an overall system that includes three general functions: (1) obtaining requests for service (see DEFINITION Section) from SDEs wishing to operate in underutilized spectrum and/or forecasting requests for such service; (2) obtaining information on the availability of underutilized spectrum and/or forecasting the availability of underutilized spectrum; and (3) allocating underutilized spectrum to service requests and transmitting information about such allocations to both the wireless operator generating the service request and the wireless operator with underutilized spectrum.

a. Structure of Block Diagram

Figures 1 and 3 show a block diagram of the components involved in System A-1. System A-1 involves four groups of components in any given geographical area.

i. Service Demand Entities

The first group comprises those components that are part of wireless networks managed by operators requesting service or SDEs 0228. These components generate requests for service and transmit such requests to an allocation system like Allocator 0044. This group includes without limitation:

(1) Stations that transmit electromagnetic signals to and receive signals from their respective wireless networks, including Mobile Stations 0078 and 0080 and a Non-Mobile Station 0082, which could include without limitation: a television set, a FM receiver, and fixed transmitter/receivers. Typically, vendors configure these stations to operate within specific radio frequency (RF) bands. In the present invention, these stations can operate across wider and/or additional RF bands, in particular, the RF bands made available by SSEs 0226. To achieve this objective, these stations include one or more antennas and other communications circuitry that enable these stations to operate over any desired and available spectrum.

(2) Transceivers that transmit signals to and receive signals from stations. The transceivers 0066, 0068, and 0070 represent the transceivers for a sample mobile operator A, another sample mobile operator B, and a sample fixed wireless operator C, respectively. Typically, vendors configure these transceivers to operate within specific RF bands. In the present invention, these transceivers can operate across wider and/or additional RF bands, in particular, the RF bands made available

by SSEs 0226. To achieve this objective, these transceivers include one or more antennas and other communications circuitry that enable these transceivers to operate over any desired and available spectrum. System A-1 can operate regardless of whether there exist one transceiver or multiple transceivers that can operate across a very wide or multiple RF band(s).

(3) Radio Frequency Channels (RFC) that represent the predetermined means by which the stations and transceivers communicate. The predetermined means include agreements about the following parameters, which include without limitation: (a) spectrum, e.g., center frequency and bandwidth; (b) transmit power; (c) modulation scheme, e.g., Frequency Modulation (FM), Quadrature Phase Shift Keying (QPSK), and Gaussian Minimum Shift Keying (GMSK); and (d) Media Access Control (MAC) scheme, e.g., Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA), along with the necessary parameters, e.g., carrier frequency for FDMA, carrier frequency and time slot for TDMA, and code, offset, and power level for CDMA. The RFCs 0072 and 0074 represent the RFCs for a sample mobile operator A and another sample mobile operator B, respectively. The RFC 0076 represents the RFC for a sample fixed wireless operator C.

(4) Gateways that perform two functions: (a) transport signals from public and private backbone networks, including without limitation the Public Switched Telephone Network (PSTN) 0084 generally used for voice communications and Packet Switched Data Network (PSDN) 0086 for data communications, the latter of which in turn includes both private networks and public networks like the Internet, to transceivers and vice versa, a function the present invention calls Information Transmission (IT); and (b) provide a link or Signaling Channel (SC) for transporting signaling information between the wireless network and the Allocator 0044, a function the present invention calls Signaling. The gateways 0052, 0054, and 0056 represent the gateways for sample mobile operator A, another sample mobile operator B, and a sample fixed wireless operator C, respectively.

(5) Brokers or other third parties (which the present invention collectively calls Brokers 0058) that can act as intermediaries between wireless networks managed by operators requesting service and the Allocator 0044. Acting as an intermediary can involve the following activities including without limitation: (a) acting simply as a conduit for transmitting service requests from one or more SDEs 0228 to the Allocator 0044; and (b) collecting and analyzing service requests from one or more SDEs 0228 and transmitting such requests to the Allocator 0044. An example of a Broker 0058 performing the first activity is a network that already has links with the SDE 0228 and Allocator 0044, which would obviate the need for the SDE 0228 to construct a separate link directly to the Allocator 0044. An example of a Broker 0058 performing the second activity is an entity in the business of collecting and transmitting service requests from SDEs 0228 to the Allocator 0044.

ii. Spectrum Supply Entities

The second group comprises those components that are part of wireless networks managed by operators with underutilized spectrum or SSEs 0226. These components identify underutilized spectrum and transmit information about such spectrum to an allocation system. This group includes without limitation:

(1) Stations that transmit signals to and receive signals from their respective wireless networks, including without limitation: Mobile Stations 0002 and 0004, Television Set 0006, and Satellite Transceiver 0008.

(2) Transceivers that transmit signals to and receive signals from stations. The transceivers 0018 and 0020 represent the transceivers for a sample mobile operator D and another sample mobile operator E, respectively. The antenna 0022 represents the antenna for a sample television operator F. The antenna 0024 represents the satellite transponder for a sample satellite operator G.

(3) RFCs that represent the predetermined means by which the stations and transceivers communicate. The predetermined means include agreements about the following parameters, which include without limitation: (a) spectrum, e.g., center frequency and bandwidth; (b) transmit power; (c) modulation scheme, e.g., FM, QPSK, and GMSK; and (d) MAC scheme, e.g., FDMA, TDMA, and CDMA, along with the necessary parameters, e.g., carrier frequency for FDMA, carrier frequency and time slot for TDMA, and code, offset, and power level for CDMA. The RFCs 0010 and 0012 represent the RFCs for a sample mobile operator D and another sample mobile operator E, respectively. The RFC 0014 represents the RFC for a sample television operator F. The RFC 0016 represents the RFC for a sample satellite operator G.

(4) Gateways that enable Information Transmission and Signaling. The gateways 0034 and 0036 represent the gateways for sample mobile operator D and another sample mobile operator E, respectively. The gateway 0038 represents the gateway for sample television operator F. The gateway 0040 represents the gateway for a sample satellite operator G.

(5) Brokers 0058 that can act as intermediaries not only between wireless networks managed by operators requesting service and the Allocator 0044, but also wireless networks managed by operators with underutilized spectrum and the Allocator 0044. These Brokers 0058 can act in the same ways as the Brokers 0058 discussed in Section A.1.a.i.(5) except they focus on dealing with underutilized spectrum. These Brokers 0058 can either: (a) specialize in acting as intermediaries between SDEs 0228 and the Allocator 0044; (b) specialize in acting as intermediaries between SSEs 0226 and the Allocator 0044; or (c) act as intermediaries among SDEs 0228, SSEs 0226, and the Allocator 0044.

iii. Monitoring Network

The third group comprises those components that are under the control of wireless networks managed by operators requesting service or SDEs 0228 and wireless networks managed by operators with underutilized spectrum or SSEs 0226. In addition, the third group comprises those components that are outside the control of such wireless networks and managed by either the operator managing the Allocator 0044 and/or third parties. These components collectively constitute a Monitoring Network (MN) 0230.

The components in the first group of SDEs 0228 described in Section A.1.a.i. generate requests for service in real-time and in advance. In contrast, to identify requests for service in real-time and in advance, the components in the third group monitor data and events outside the control of or inaccessible to SDEs 0228. In most current wireless networks, the components in the first group obtain and evaluate information to generate requests for service by evaluating data at OSI Layer 1 through Layer 3, the physical layer through routing layer, respectively. The components in the third group obtain and evaluate information to forecast requests for service by evaluating data at OSI Layer 1 through Layer 7, the physical layer through application layer, respectively.

The components in the second group of SSEs 0226 described in Section A.1.a.ii. identify underutilized spectrum in real-time and in advance. In contrast, to identify underutilized spectrum in real-time and in advance, the components in the third group monitor data and events outside the control of or inaccessible to SSEs 0226. Some components in existing wireless networks can evaluate data at OSI Layer 1 through Layer 3, the physical layer through routing layer, respectively. The components in the fourth group can obtain and evaluate information to forecast requests for service by evaluating data at OSI Layer 1 through Layer 7, the physical layer through application layer, respectively.

For example, System A-1 can forecast requests for service by a SDE 0228 by evaluating the size of a file requested by a station subscribing a service provided by SDE 0228. Assume that the SDE 0228 is fully utilizing the spectrum in which it is licensed to operate at time 0900 and a station requests a file that the SDE 0228 cannot service. System A-1 can forecast the SDE 0228 request for service only by evaluating data about the file requests. Such data can reside in OSI layers like Layer 7, which cannot

be evaluated by hardware and software operating at Layer 1 through Layer 3. The components in the third group can evaluate such data at the higher layers.

The components in the third group include without limitation:

(1) Monitoring stations under the control of SDEs 0228 and SSEs 0226 that monitor the parameters needed by the Allocator 0044 to identify service requests and underutilized spectrum in real-time and in advance. The present invention discusses these parameters in Sections B.1 and C.4. The monitoring stations can be located in any or all SDEs 0228 and any or all SSEs 0226.

For a representative SDE 0228, the monitoring stations can include without limitation: (a) Autonomous Monitoring Stations (AMS) 0096, which is hardware and software that can monitor such parameters and can be located anywhere within the SDE's network, including without limitation the following locations: (i) the network's transceivers that transmit signals to and receives signals from stations; and (ii) any other location within the network's geographical area; and (b) Embedded Monitoring Stations (EMS) 0094, which is hardware and software that can monitor such parameters and is located at stations, either located near them, attached to them, or embedded inside them.

For one representative SSE 0226, the monitoring stations can include without limitation: (a) Autonomous Monitoring Stations (AMS) 0092, which is hardware and software that can monitor such parameters and can be located anywhere within the SSE's network, including without limitation the following locations: (i) the network's transceivers that transmit signals to and receives signals from stations; and (ii) any other location within the network's geographical area; and (b) Embedded Monitoring Stations (EMS) 0090, which is hardware and software that can monitor such parameters and is located at stations, either located near them, attached to them, or embedded inside them.

(2) Monitoring stations outside the control of SDEs 0228 and SSEs 0226 that monitor the parameters needed by the Allocator 0044 to identify service requests in real-time and in advance and underutilized spectrum in real-time and in advance. The monitoring stations can include without limitation: (1) Allocator Monitoring Node (AMN) 0224, which is hardware and software that can monitor such parameters and is located at the Allocator 0044; and (2) External Monitoring Stations (EXMS) 0098, which is hardware and software that can monitor such parameters and is located outside the Allocator 0044.

System A-1 may need EXMSs 0098 where AMS 0092 and EMS 0090 may not exist. For example, when monitoring Unlicensed Channels (see Section A.1.b.iii.(3)(c)), System A-1 needs EXMSs 0098 because no SSE 0226 operates in such Channels and thus no AMS 0092 or EMS 0090 can exist. The operator managing the Allocator 0044 and/or a third party would need its own monitoring stations like EXMSs 0098 to identify underutilized spectrum in real-time and in advance.

iv. Allocator 0044

The fourth group comprises those components involved in allocating underutilized spectrum to service requests and transmitting information about such allocations to both the SDE 0228 generating the service request and the SSE 0226 with underutilized spectrum. This group includes without limitation:

(1) An Allocator 0044, which performs the overall allocation function, which comprises the functions performed by the three following entities.

(2) A Service Request Engine (SRE) 0050, which is hardware and software that is part of the Allocator 0044 that identifies service requests in real-time and in advance, and processes and stores information about service requests and/or forecasted demand for service.

(3) A Spectrum Identification Engine (SIE) 0046, which is hardware and software that is part of the Allocator 0044 that identifies underutilized spectrum in real-time and in advance, and processes and stores information about underutilized spectrum and/or forecasted supply of underutilized spectrum.

(4) A Spectrum Allocation Engine (SAE) 0048, which is hardware and software that is part of the Allocator 0044 that attempts to match underutilized spectrum with service requests and transmits all relevant information to the SDE 0228 and SSE 0226.

b. Functional Relationships in Block Diagram

i. Overall Functional Relationships

At an overall level, the three groups are related to each other in the following ways.

(1) The gateways 0052, 0054, and 0056 of the wireless operators needing spectrum (SDEs 0228) and/or Brokers 0058 generate requests for service and transmit such requests to the SRE 0050. In addition, the monitoring stations, including 0096, 0094, 0098, and 0260, identify requests for service in real-time and in advance. Also, the SRE 0050 forecasts demand for service.

(2) The gateways 0034, 0036, 0038, and 0040 of the wireless operators with underutilized spectrum (SSEs 0226) and/or Brokers 0058 identify underutilized spectrum and transmit information about such spectrum to the SIE 0046. In addition, the monitoring stations, including 0092, 0090, 0098, and 0224, identify underutilized spectrum in real-time and in advance. Also, the SIE 0046 forecasts supply of underutilized spectrum.

(3) The Allocator 0044 matches underutilized spectrum with service requests. The Allocator 0044 can match:

(a) Underutilized spectrum, including such spectrum identified by the SSEs 0226, Brokers 0058, and SIE 0046 in real-time, such spectrum identified by the SSEs 0226 and/or Brokers 0058 in advance, and such spectrum forecasted by the SIE 0046; and

(b) Service Requests, including such requests transmitted by SDEs 0228, Brokers 0058, and SRE 0050 in real-time, such requests transmitted by SDEs 0228 and/or Brokers 0058 in advance, and such requests forecasted by the SRE 0050.

After the Allocator 0044 performs such matching, the Allocator 0044 transmits the information needed by the SDEs 0228 to operate in such underutilized spectrum by utilizing underutilized frequency, time, code, space, and/or polarization resources. In addition, the Allocator 0044 transmits the information needed by the SSEs 0226 to ensure that they do not utilize the frequency, time, code, space, and/or polarization resources assigned by the Allocator 0044 to the SDEs 0228.

ii. Functional Relationships Regarding Service Requests

System A-1 includes the functions of allocating underutilized spectrum to any given SDE 0228 for part or all of its traffic. That is, a SDE 0228 like Mobile Operator A could transmit a request through Gateway 0050 to an Allocator 0044 to allocate underutilized spectrum in the following ways, including without limitation:

(1) Total Allocation

The Allocator 0044 could allocate underutilized spectrum from the SDE's network, some other wireless network, and/or some combination of all wireless networks to *all* signals that a SDE 0228 receives from a public or private backbone network (e.g., PSTN 0084, PSDN 0086, or Virtual

Private Network (VPN)) on one side of its gateway and from its stations on the other side of its gateway (Total Allocation). Even where the SDE 0228 may have sufficient capacity on its own network for all signals to and from its stations, the SDE 0228 may still utilize the Allocator 0044 to assign some or all of these signals to underutilized spectrum from other wireless networks. A SDE 0228 might request such service in cases, for example, where the Allocator 0044 has functionality that the SDE 0228 does not possess.

(2) Fractional Allocation

The Allocator 0044 could allocate underutilized spectrum from the SDE's network, some other wireless network, and/or some combination of all wireless networks to *some* signals that a SDE 0228 receives from a public or private backbone network (e.g., PSTN 0084, PSDN 0086, or VPN) on one side of its gateway and from its stations on the other side of its gateway (Fractional Allocation). A SDE 0228 could request an Allocator 0044 to allocate the following combinations of signals the SDE 0228 wants to transport to and from its stations:

| Constant Bit Rate Traffic | Variable Bit Rate Traffic |
|---|---|
| All | All |
| All | Some |
| All | Excess |
| All | None |
| Some | All |
| Some | Some |
| Some | Excess |
| Some | None |
| Excess | All |
| Excess | Some |
| Excess | Excess |
| Excess | None |
| None | All |
| None | Some |
| None | Excess |

The first combination of "All CBR Traffic, All VBR Traffic" represents the special case of Total Allocation. All other combinations listed above represent cases of Fractional Allocation. The combination of "None CBR Traffic, None VBR Traffic" represents a case in which the SDE 0228 does not utilize the Allocator 0044 for any functions.

Constant Bit Rate (CBR) traffic requires a fixed bit rate so that the operator transports data at a constant rate. Variable Bit Rate (VBR) traffic generally requires some specified average capacity (bits per second), but does not require that all data be transmitted at a constant rate. CBR and VBR traffic impose different requirements on the creation and maintenance of links between nodes of a network exchanging traffic. CBR transmissions are generally *circuit switched*, meaning that a dedicated physical or virtual channel is reserved or created for the exclusive use of the network nodes that are exchanging traffic. An operator assigns the channel to the nodes for some specified time interval negotiated beforehand or through some signaling protocol such as Signaling System 7 (SS7). By contrast, VBR transmissions are generally *packet switched*, meaning that channels between nodes are only dedicated to those nodes for the time needed to exchange some Protocol Data Unit (PDU) - a block of data whose size is defined by some standard protocol agreed to by all nodes participating in a given network. Examples of VBR protocols include without limitation: 802.x (Ethernet) protocols, X.25, Transmission Control Protocol/Internet Protocol (TCP/IP), and User Datagram Protocol/Internet Protocol (UDP/IP).

"All" means all signals of a particular type (either CBR or VBR) a SDE 0228 wants to transport to and from its stations.

"Some" means some fraction of those signals of a particular type a SDE 0228 wants to transport to and from its stations, regardless of whether it has more capacity available on its own network.

"Excess" means those signals of a particular type a SDE 0228 wants to transport to and from its stations, but cannot because it has no more capacity available on its own network. Excess represents a special case of the "Some" category.

"None" means no signals of a particular type a SDE 0228 wants to transport to and from its stations.

For example, the combination of "All VBR, Excess CBR" means that the SDE 0228 requests the Allocator 0044 to assign underutilized spectrum to: (1) all VBR traffic that a SDE 0228 wants to transport, regardless of whether the SDE 0228 has sufficient capacity on its own network; and (2) only that CBR traffic that a SDE 0228 wants to transport, but cannot because it has no more capacity available on its own network.

iii. Functional Relationships Regarding Spectrum Identification

System A-1 includes the functions of identifying underutilized spectrum among Incumbent Licensees. The functional relationships regarding the identification of underutilized spectrum include without limitation:

(1) Timing of Identification

System A-1 can identify underutilized spectrum either in real-time or in advance:

In practice, in order for a SDE 0228 to operate in any underutilized spectrum, System A-1 must identify such underutilized spectrum in advance. To ensure that the transmission of the SDE 0228 does not interfere with the transmission of the SSE 0226, System A-1 must know the start time and stop time of the underutilized spectrum the SSE 0226 is making available for utilization by a Sharing Operator. Therefore, the SSE 0226 must provide and/or System A-1 must forecast the stop time of the underutilized spectrum.

However, the present invention defines "real-time" identification of underutilized spectrum as identification of underutilized spectrum in response to or concurrently with the reception of a service request by the Allocator 0044.

The present invention defines identification of underutilized spectrum "in advance" as underutilized spectrum identified before reception of a service request by the Allocator 0044.

System A-1 can identify underutilized spectrum in real-time and in advance in the following ways, including without limitation:

(a) SSE 0226 identifies underutilized spectrum and transmits parameters regarding such spectrum to SIE 0046.

(b) AMS 0092 identifies underutilized spectrum and transmits parameters regarding such spectrum to SIE 0046.

(c) EMS 0090 identifies underutilized spectrum and transmits parameters regarding such spectrum to SIE 0046.

(d) AMN 0224 identifies underutilized spectrum and transmits parameters regarding such spectrum to Estimator/Predictor 0206.

(e) EXMS 0098 identifies underutilized spectrum and transmits parameters regarding such spectrum to SIE 0046.

(2) Type of Underutilized Spectrum by Access Method

System A-1 utilizes different techniques for identifying underutilized spectrum depending on the method employed by an Incumbent Licensee for controlling access by multiple parties to the spectrum in which it is licensed to operate. The present invention divides such methods into the following categories, which include without limitation:

(a) Fixed Assignment

The present invention defines fixed assigned (FA) channels as channels to which specific frequency, time, code, space, and polarization resources have been dedicated. Examples include without limitation: analog and digital television broadcasters, AM and FM radio broadcasters, satellite broadcasters, and point-to-point microwave and millimeterwave backhaul links.

(b) Demand Assignment

The present invention defines demand assigned (DA) channels as channels employed in networks where stations demand resources through some dedicated signaling channel from certain network. entities responsible for allocating time, frequency, code, space, and polarization resources. Examples of networks employing DA channels include without limitation: CMRS operators employing FDMA, TDMA, or CDMA transmission protocols; land mobile radio (LMR) systems employing trunked FM or single sideband (SSB) channels; and wireless systems employing resource auction multiple access (RAMA) algorithms.

(c) Random Assignment

The present invention defines random access (RA) channels as channels employed in networks where stations contend for access to the channel using methods that may lead to overlapping or colliding simultaneous transmissions, which in turn may require stations to retransmit after a random time period to reduce the probability of colliding again. Different types of random access schemes can include without limitation: fixed schemes in which stations transmit without coordinating access with other stations; or adaptive channel-sensing schemes in which stations first sense the channel to gain channel state information. Examples of networks that employ fixed RA schemes include without limitation: networks that employ pure ALOHA, slotted ALOHA, and group random access protocols. Examples of networks that employ adaptive channel-sensing RA schemes include without limitation: networks that employ persistent and non-persistent Carrier Sense Multiple Access (CSMA), CSMA with Collision Detection (CSMA/CD), packet reservation multiple access (PRMA), and busy tone multiple access (BTMA) protocols.

In System A-1, the present invention employs in all three categories the following hardware and software to identify underutilized spectrum: AMS 0092, EMS 0090, AMN 0224, and EXMS 0098. This hardware and software monitor certain parameters discussed in Section C that may be located at and collected from the following locations, including without limitation: stations like 0002, RFCs like 0010, transceivers like 0018, and gateways like 0034.

(3) Type of Underutilized Spectrum by Control Over Access

Control over access to spectrum can be divided into the following categories, including without limitation:

(a) Exclusive Channels

Exclusive Channels represent spectrum licensed to one or more operators, each of which controls how its stations access the spectrum. For example, the U.S. FCC licenses the 824-849 MHz band for exclusive use by one CMRS operator in a given geographical area. That CMRS operator controls how its stations access the 824-849 MHz band.

Stations access Exclusive Channels through any one of the three multi-access types: fixed assignment, demand assignment, and random assignment.

(b) Shared Channels

Shared Channels represent spectrum licensed to a wireless service not under the control of any operator. For example, the U.S. FCC licenses the 50-54 MHz band, among other bands, for use by Amateur Radio Service. Any individual passing an examination can receive a license to operate Amateur Radio Service. Each licensed amateur operator can access the spectrum licensed for amateur radio service without obtaining permission of any centralized entity.

Stations access Shared Channels through random assignment.

(c) Unlicensed Channels

Unlicensed Channels represent spectrum not licensed to any wireless service.

Currently, stations are not licensed to access Unlicensed Channels. If regulators permit SDEs 0226 to access Unlicensed Channels, the stations subscribing to services provided by such SDEs 0226 could access such Channels through any one of the three multi-access types: fixed assignment, demand assignment, and random assignment.

The present invention draws the distinction among Exclusive Channels, Shared Channels, and Unlicensed Channels for at least two reasons. First, identifying underutilized spectrum will differ among such channel categories.

- Exclusive Channels. System A-1 identifies underutilized spectrum in Exclusive Channels by obtaining parameters about such spectrum from the operator controlling access to the spectrum. System A-1 obtains such parameters from hardware and software under the control of SSEs 0228 like AMS 0092 and EMS 0090 and hardware and software not under the control of SSEs 0228 like AMN 0224 and EXMS 0098.

- Shared Channels. System A-1 identifies underutilized spectrum in Shared Channels by obtaining parameters about such spectrum from hardware and software not under the control of SSEs 0228 like AMN 0224 and EXMS 0098. Because no centralized entity typically controls access to Shared Channels, System A-1 must rely on such hardware and software to identify underutilized spectrum.

- Unlicensed Channels. System A-1 identifies underutilized spectrum in Unlicensed Channels by obtaining parameters about such spectrum from hardware and software like AMN 0224 and EXMS 0098. Because no incumbent Licensee controls access to Unlicensed Channels, System A-1 must rely on the following hardware and software to monitor usage of such Channels, including without limitation: EMSs 0090 that typically operate in channels other than Unlicensed Channels; AMN 0224 located at the Allocator 0044; and EXMS 0098 managed by either the operator managing the Allocator 0044 and/or third parties.

Second, auctioning underutilized spectrum in Shared Channels and Unlicensed Channels will differ from auctioning underutilized spectrum in Exclusive Channels.

- Shared Channels. Because no centralized entity controls access to Shared Channels, there exist no entity that can change over time an ask price for operating in Shared Channels. While an association of users licensed to operate in Shared Channels and/or a regulatory agency like the FCC could set a fixed ask price, any system of ask prices that does not reflect varying supply of underutilized spectrum will not utilize such spectrum efficiently.

- Unlicensed Channels. Because no centralized entity controls access to Unlicensed Channels, there exist no entity that can change over time an ask price for operating in Unlicensed Channels. While a regulatory agency like the FCC could set a fixed ask price, any system of ask prices that does not reflect varying supply of underutilized spectrum will not utilize such spectrum efficiently.

iv. Functional Relationships Regarding Spectrum Allocation

(1) An Allocator 0044, which performs the overall allocation function, which comprise the functions performed by the three following entities.

(2) A Service Request Engine (SRE) 0050, which performs the functions of validating and processing raw information associated with requests for service, including without limitation: time constraints; performance requirements; reliability and availability requirements; station locations and capabilities; and traffic flow metrics. Such information may come from SDEs 0228 or a MN 0230, which can include without limitation: AMS 0096, EMS 0094, AMN 0224, and EXMS 0098. The SRE 0050 may also forecast demand for service using information provided by or derived from any other source, including without limitation: SSEs 0226, SDEs 0228, a MN 0230.

(3) A Spectrum Identification Engine (SIE) 0046, which performs the functions of validating and processing raw information associated with supply of underutilized spectrum, including without limitation: any time, code or modulation, space, or polarization constraints associated with using such spectrum. Such information may come from SSEs 0226 or a MN 0230, which can include without limitation: AMS 0092, EMS 0090, AMN 0224, and EXMS 0098. The SIE 0046 may also forecast supply of underutilized spectrum using information provided by or derived from any other source, including without limitation: SSEs 0226, SDEs 0228, and/or a MN 0230.

(4) A Spectrum Allocation Engine (SAE) 0048 that includes hardware and software and implements algorithms, which perform a number of dynamic resource allocation functions, including without limitation:

(a) Identify potential partitions of available channel resources that could map into service requests.

(b) Evaluate both the performance and utility of potential network designs that employ candidate channel mappings.

(c) Select optimal or suboptimal channel mappings that meet some goal, which includes without limitation the following objectives: performance, utility, and/or financial.

(d) If desired or appropriate, exchange information with SDEs 0228 and SSEs 0226 in real-time to modify parameters regarding service requests and underutilized spectrum, for example, asking if SDEs 0228 want to raise their bids for underutilized spectrum if demand is high and supply is low.

(e) If desired or appropriate, exchange information on factors like pricing with SDEs 0228 and SSEs 0226 in real-time to enable SDEs 0228 and SSEs 0226 to change the quantity of their demand for service and supply of underutilized spectrum, respectively.

- Shared Channels. Because no centralized entity controls access to Shared Channels, there exist no entity that can change over time an ask price for operating in Shared Channels. While an association of users licensed to operate in Shared Channels and/or a regulatory agency like the FCC could set a fixed ask price, any system of ask prices that does not reflect varying supply of underutilized spectrum will not utilize such spectrum efficiently.

- Unlicensed Channels. Because no centralized entity controls access to Unlicensed Channels, there exist no entity that can change over time an ask price for operating in Unlicensed Channels. While a regulatory agency like the FCC could set a fixed ask price, any system of ask prices that does not reflect varying supply of underutilized spectrum will not utilize such spectrum efficiently.

iv. Functional Relationships Regarding Spectrum Allocation

(1) An Allocator 0044, which performs the overall allocation function, which comprise the functions performed by the three following entities.

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(3) A Spectrum Identification Engine (SIE) 0046, which performs the functions of validating and processing raw information associated with supply of underutilized spectrum, including without limitation: any time, code or modulation, space, or polarization constraints associated with using such spectrum. Such information may come from SSEs 0226 or a MN 0230, which can include without limitation: AMS 0092, EMS 0090, AMN 0224, and EXMS 0098. The SIE 0046 may also forecast supply of underutilized spectrum using information provided by or derived from any other source, including without limitation: SSEs 0226, SDEs 0228, and/or a MN 0230.

(4) A Spectrum Allocation Engine (SAE) 0048 that includes hardware and software and implements algorithms, which perform a number of dynamic resource allocation functions, including without limitation:

(a) Identify potential partitions of available channel resources that could map into service requests.

(b) Evaluate both the performance and utility of potential network designs that employ candidate channel mappings.

(c) Select optimal or suboptimal channel mappings that meet some goal, which includes without limitation the following objectives: performance, utility, and/or financial.

(d) If desired or appropriate, exchange information with SDEs 0228 and SSEs 0226 in real-time to modify parameters regarding service requests and underutilized spectrum, for example, asking if SDEs 0228 want to raise their bids for underutilized spectrum if demand is high and supply is low.

(e) If desired or appropriate, exchange information on factors like pricing with SDEs 0228 and SSEs 0226 in real-time to enable SDEs 0228 and SSEs 0226 to change the quantity of their demand for service and supply of underutilized spectrum, respectively.

(f) Transmit information about the decision made by the Allocator 0044 to both the SDEs 0228 generating the service request and the SSEs 0226 identifying underutilized spectrum. The Allocator 0044 can decide either to: (i) allocate channel resources; or (ii) not allocate channel resources.

(g) Enable billing transactions between SDEs 0228 and SSEs 0226.

(h) Maintain a common reference time base for all entities utilizing the Allocator 0044, including without limitation: agreements to monitor and reference time bases associated with other services, including without limitation: Global Positioning System (GPS); time bases which may be derived from signals of opportunity such as digital broadcasters; or time bases accessible directly from CMRS operators.

d. Discussion of System A-1

In general, System A-1 supports cases where the wireless operator generating requests for service or SDE 0228 is different from the wireless operator with underutilized spectrum or SSE 0226. The SSE 0026 could offer the same wireless service as the SDE 0228 or a different service than the SDE 0228. For example, if the SDE 0228 is a CMRS operator like Verizon Wireless, the SSE 0226 could be another CMRS operator like AT&T Wireless or a Private Operational Fixed Microwave Service (POFMS) operator like WorldCom.

However, System A-1 could support cases where the SSE 0226 and SDE 0228 is the same entity. That is, a CMRS operator like Verizon Wireless could request that an Allocator 0044 in Figure 1 allocates part or all of Verizon Wireless's traffic to the spectrum in which Verizon Wireless is licensed to operate. A SDE 0228 might request such service in cases, for example, where the Allocator 044 has functionality that the SDE 0228 does not possess.

In addition, a wireless operator can be a SDE 0228 at one time and a SSE 0226 immediately after. That is, a wireless operator at time 0900 can experience demand that exceeds supply and thus generate a request for service and at time 0901 can experience demand that falls short of supply and thus have underutilized spectrum. Moreover, a wireless operator can be a SDE 0228 and SSE 0226 at the same time. That is, a wireless operator at time 0900 can generate a request for service because demand exceeds supply at time 0900. However, if it can determine at time 0900 that it will have underutilized spectrum at time 0915, it can transmit information about such underutilized spectrum at time 0900.

The wireless networks A-G are examples of networks granted a license from a regulatory agency, e.g., the FCC in the United States and the Office of Telecommunications (Oftel) in the United Kingdom, to provide a wireless service within a given amount of spectrum within a given geographical space subject to certain restrictions.

The wireless networks A-G are examples of networks that transport electromagnetic signals that can carry data types, which include without limitation: voice, audio, video, images, and data. These networks transport such signals to stations, including: mobile stations, e.g., 0002 and 0004, or fixed stations, e.g., 0006 and 0008. Examples of such networks include without limitation: the current second generation (2G) cellular/PCS systems (including without limitation: Global System for Mobile communications (GSM), IS-95, IS-136, and Specialized Mobile Radio Service (SMRS)); the proposed third generation (3G) cellular/PCS systems (including without limitation: W-CDMA, cdma2000, General Packet Radio Service (GPRS), and Enhanced Data Rates for GSM Evolution (EDGE)); broadcast networks (including without limitation: analog and digital terrestrial TV and radio, satellite TV and radio); wireless Local Area Networks (LAN) (including without limitation: IEEE 802.11a and IEEE 802.11b); fixed broadband wireless Wide Area Networks (WAN) (including without limitation: IEEE 802.16, Multichannel Multipoint Distribution Services (MMDS), and Local Multipoint Distribution Services (LMDS)); peer-to-peer wireless ad hoc networks (MANET) (including without limitation: services employing Bluetooth protocols); and messaging/paging networks (including without limitation: networks providing services such as Ardis, Mobitex, Ricochet, Cellular Digital Packet Data (CDPD), and Tetra)..

In most markets, entities increase or decrease their demand for goods/services when the price falls or rises, respectively, and entities increase or decrease their supply of goods/services when the price rises or falls, respectively. System A-1 enables SDEs 0228 and SSEs 0226 to respond to price changes by changing the quantity of their demand for service or supply of underutilized spectrum. This functionality has the advantage of enabling the present invention to reduce the probability that demand exceeds supply of spectrum by utilizing market forces. System A-1 provides such functionality by exchanging with SDEs 0228 and SSEs 0226 information they need to make decisions to adjust demand and supply, including without limitation: pricing, numbers of bids and offers, and historical data on demand-supply imbalances. System A-1 includes both: (1) the components utilized by SDEs 0228 and SSEs 0226 to make decisions about adjusting their demand for service or supply of underutilized spectrum; and (2) the methods utilized by SDEs 0228 and SSEs 0226 to make such decisions.

The present invention covers the identification of any and all underutilized spectrum and allocation of such spectrum. While the present invention discusses wireless systems that transmit electromagnetic signals, in particular, radio waves, the present invention applies to any type of electromagnetic signal.

## A.2. Overall Method

The present invention includes an overall method of enabling entities requesting service to operate in any underutilized spectrum.

**METHOD A-2:** *Overall Method of Enabling Entities Requesting Service to Operate in Underutilized Spectrum*

Method A-2 is an overall method of obtaining service requests, identifying underutilized spectrum, and matching underutilized spectrum to service requests.

a. Relationship to System A-1

Method A-2 is the process by which the present invention enables wireless networks requesting service (SDEs 0228) to operate in underutilized spectrum. System A-1 is the system of components that enable the process outlined in Method A-2.

b. Steps for Executing Method

In the preferred embodiment of the present invention, Method A-2 includes without limitation the following steps:

At Step 0100, Monitoring Network 0230 identifies in advance one or more service requests and underutilized spectrum. Monitoring stations under the control of SDEs 0228 and SSEs 0226 like the ones described in Section A.1.a.i.(1) identify in advance spectrum requests and underutilized spectrum. Monitoring stations not under the control of SDEs 0228 and SSEs 0226 like the ones described in Section A.1.a.i.(2) identify in advance service requests and underutilized spectrum.

At Step 0102, monitoring stations that are part of Monitoring Network 0230 transmit to the Allocator 0044 information about service requests and underutilized spectrum identified in advance.

At Step 0104, SRE 0050, which is part of Allocator 0044, processes and stores information about service requests identified in advance.

At Step 0106, SIE 0046, which is part of Allocator 0044, processes and stores information about underutilized spectrum identified in advance.

At Step 0108, SRE 0050 forecasts the demand for service by SDEs 0228.

At Step 0110, SIE 0046 forecasts the supply of underutilized spectrum from SSEs 0226.

At Step 0112, a particular SDE 0228 generates a service request and transmits such request to the SRE 0050.

At Step 0114, SRE 0050 processes real-time (RT) service request.

At Step 0116, SRE 0050 estimates the total demand for service requests based on inputs from Steps 0104, 0108, and 0114.

At Step 0118, SRE 0050 formats the data generated by Step 0116 and transmits the data to SAE 0048.

At Step 0120, SIE 0046 identifies in real-time underutilized spectrum.

At Step 0122, SIE 0046 estimates the total supply of underutilized spectrum based on inputs from Steps 0106, 0110, and 0120.

At Step 0124, SIE 0046 formats the data generated by Step 0122 and transmits the data to SAE 0048.

At Step 0126, SAE 0048 identifies potential partitions of available channel resources that could map into service requests.

At Step 0128, SAE 0048 evaluates both the performance and utility of potential network designs that employ candidate channel mappings.

At Step 0130, SAE 0048 exchanges information with SDEs 0228 and SSEs 0226 in real-time to modify parameters regarding service requests and underutilized spectrum, if needed or appropriate.

At Step 0132, SAE 0048 exchanges information on factors like pricing with SDEs 0228 and SSEs 0226 in real-time to enable SDEs 0228 and SSEs 0226 to change the quantity of their demand for service and supply of underutilized spectrum, respectively. SAE 0048 can exchange such information in real-time so that SDEs 0228 and SSEs 0226 change their demand for service and supply of underutilized spectrum immediately. Alternatively, SAE 0048 can exchange such information in advance so that SDEs 0228 and SSEs 0226 can change in advance their future demand for service and future supply of underutilized spectrum, respectively. An example of how a SSE 0226 could change the supply of underutilized spectrum it makes available to the SAE 0048 is by changing the composition of traffic on its network, e.g., delaying VBR traffic like email packets on its network and thus increasing its supply of underutilized spectrum when it receives information that the price of spectrum rises significantly.

At Step 0134, SAE 0048 selects optimal or suboptimal channel mappings that meet some goal, which includes without limitation the following objectives: performance, utility, and/or financial.

At Step 0136 SAE 0048 transmits information about allocation based on Step 0132 to both the SDEs 0228 generating the service request and the SSEs 0026 identifying underutilized spectrum.

At Step 0138, SAE 0048 enables billing transactions between SDEs 0228 and SSEs 0226.

At Step 0140, SAE 0048 transmits information about a common reference time base for all entities utilizing the Allocator 0044, including without limitation: agreements to monitor and reference time bases associated with other services, including without limitation: Global Positioning System (GPS); time bases which may be derived from signals of opportunity such as digital broadcasters; or time bases accessible directly from CMRS operators.

c. Discussion

In an alternative embodiment of the present invention, Method A-2 can enable SDEs 0228 to transport information over not only the channel resources of an Incumbent Licensee, but also over the actual network of the Incumbent Licensee. That is, after identifying underutilized spectrum and allocating underutilized spectrum to service requests, Method A-2 enables a SDE 0228 to transport information to the stations subscribing to its service through the network hardware, software, and algorithms of an Incumbent Licensee, including without limitation, its transceivers.

In another alternative embodiment of the present invention, Method A-2 can enable hardware and software located at stations to identify underutilized spectrum and operate in such spectrum. While the present invention enables such operation, the preferred embodiment of Method A-2 generates the following advantages:

i. It is less costly for Incumbent Licensees to provide information about underutilized spectrum to one centralized system like Apparatus A-3 than to a large number of distributed stations.

ii. Distributed stations will be less able to identify underutilized spectrum in advance, because it will be easier for one centralized system like Apparatus A-3 than for large number of stations to cooperate with Incumbent Licensees to generate and obtain such information.

iii. A centralized system like Apparatus A-3 is better able to administer an auction or exchange process than distributed stations.

iv. Because distributed stations would have to utilize some type of random assignment system, they would not fully utilize all available underutilized spectrum. When collisions occur, both parties must back off and retransmit. However, the underutilized spectrum available at the time of the collision would be wasted.

In yet another alternative embodiment of the present invention, Method A-2 can allocate underutilized spectrum by utilizing a combination of a centralized and distributed system.

A.3. Apparatus for Obtaining Service Requests, Identifying Underutilized Spectrum, and Allocating Underutilized <u>Spectrum to Service Requests</u>

The present invention includes an apparatus for obtaining service requests, identifying underutilized spectrum, and allocating such spectrum to service requests. The apparatus collects and processes: (1) data about spectrum utilization along with forecasted supply of underutilized spectrum; and (2) data about service requests along with forecasted demand for service. The apparatus allocates channels that will enable available spectrum to fulfill requests for service.

The information utilized by the overall allocation process may be deterministic or stochastic. In the deterministic case, the Allocator 0044 knows with certainty the availability of underutilized spectrum and the requirements of service requests. In the stochastic case, the Allocator 0044 does not know with certainty the availability of underutilized spectrum or the requirements of service requests. The uncertainty may be due to errors or incompleteness in the data regarding underutilized spectrum or service requests themselves or may be due to uncertainty in a prediction process that attempts to forecast availability of underutilized spectrum and/or requirements of service requests.

In the stochastic case, the Allocator 0044 may allocate underutilized spectrum to reflect the probability of interference. For example, suppose that a SSE 0226 is licensed to operate two channels of equal bandwidth and that it is willing to share the channels with a SDE 0228 transmitting at sufficiently low power levels. The transmissions of the SDE 0228 should not cause undue interference with the transmissions of the SSE 0226 because of the lower power levels employed by the SDE 0228. However, the transmissions of the SDE 0228 will probably interfere with the transmissions of the SDE 0228 if the latter transmits at the same time as the SSE 0226. If the SDE 0228 is attempting to transmit low priority packet data, it can retransmit in case of collision with the transmission of the SSE 0226. If the SIE 0046 forecasts that Channel A, for example, will be randomly available 20% of the time and

Channel B will be randomly available 50% of the time, the Allocator 0044 could use these percentages to determine the probabilities of collision and allocate the shared spectrum accordingly.

**APPARATUS A-3**: *Apparatus for Identifying Underutilized Spectrum and Allocating Spectrum in Response to Service Demands.*

Apparatus A-3 is an apparatus that implements the hardware, software, and algorithmic requirements of Method A-2. Apparatus A-3 comprises three principal blocks (see Figure 3): a Spectrum Identification Engine (SIE) 0046, a Spectrum Allocation Engine (SAE) 0048, and a Spectrum Request Engine (SRE) 0050.

a. Relationship to Overall Figure 1

Apparatus A-3 implements the function of Allocator 0044 in Figure 1. SDEs 0228 include without limitation the group shown in Figure 1 with points-of-presence (POPs) represented by gateways 0052, 0054, and 0056. SSEs 0226 in Figure 3 include without limitation the group shown in Figure 1 with POPs presence represented by gateways 0034, 0036, 0038, and 0040. The MN 0230 shown in Figure 3 includes without limitation: AMS 0092, EMS 0090, AMS 0096, EMS 0094, AMN 0224, and EXMS 0098.

b. Structure of Block Diagram

The Allocator 0044 consists of a SIE 0046, a SAE 0048, and a SRE 0050. The Allocator 0044 implements the functions described in Method A-2.

The SIE 0046 consists of an Estimator 0200, an Estimator/Predictor 0206, a Predictor 0202, and an Overall Estimator 0204. The SIE 0046 implements the functions described in Method A-2. The Estimator 0200 obtains raw spectrum availability data, validates the information, and estimates the values of any missing data that will be required by the SAE 0048. The Estimator/Predictor 0206 implements the same functions as the Estimator 0200, but is also capable of predicting spectrum availability based on historical, current, and other data. The Predictor 0202 is capable of predicting spectrum availability based on historical, current, and other data. The Overall Estimator 0204 receives from components 0200, 0206, and 0202 multiple estimates and/or predictions and forms definitive resource availability estimates.

The SAE 0048 consists of a Resource-to-Demand Mapper 0214, an Optimizer 0212, and an Exchange/Synchronizer 0210. The SAE 0048 implements the functions described in Method A-2. The Resource-to-Demand-Mapper 0214 defines mappings between available resources and service demand. The Optimizer 0212 evaluates potential resource-service associations and allocates resources to services based on its evaluations. The Exchange/Synchronizer 0210 enables free market exchange of resources under arbitrary pricing mechanisms and provides participating SDEs 0228 and SSEs 0226 with a common time base to coordinate transactions and usage of spectrum.

The SRE 0050 consists of an Estimator 0218, an Estimator/Predictor 0224, Predictor 0216, and an Overall Estimator 0220. The SRE 0050 implements the functions described in System A-1. The Estimator 0218 obtains raw service demand data, validates the information, and estimates the values of any missing data that will be required by the SAE 0048. The Estimator/Predictor 0224 implements the same functions as the Estimator 0218, but is also capable of predicting service demand based on historical, current, and other data. The Predictor 0216 is capable of predicting service demand based on historical, current, and other data. The Overall Estimator 0220 receives from components 0218, 0224, and 0216 multiple estimates and/or predictions and forms definitive service demand estimates.

c. Functional Relationships in Block Diagram

SSE 0226 provides raw spectrum availability data to Estimator 0200 via a dedicated signaling link 0250. A Monitoring Network 0230 provides via a dedicated signaling link 0262 raw data on any spectrum availability observations it has made to the Estimator/Predictor 0206. A Monitoring Network 0230 provides via a dedicated signaling link 0264 raw data on service demand observations it has made to the Estimator/Predictor 0222, which predicts availability of any spectrum of interest that may be affected.

SDEs 0228 may also provide via a dedicated signaling link 0256 raw data on current or anticipated service demands to Predictor 0202, which also predicts availability of any spectrum of interest that may be affected.

Overall Estimator 0204 processes all estimates and predictions and forms definitive and unambiguous spectrum availability estimates for use by the SAE 0048. Estimates that are ambiguous are grouped and associated with a set of statistics, including without limitation: expected values and other central moments and estimated probability distributions. All estimates are sent together with any associated statistics together to the Resource-to-Demand Mapper 0214 within the SAE 0048.

SDE 0228 provides raw service demand data to Estimator 0218 via a dedicated signaling link 0260. A Monitoring Network 0230 provides via a dedicated signaling link raw data on any service demand it has made to the Estimator/Predictor 0222 via dedicated signaling link 0264. A Monitoring Network 0230 provides via a dedicated signaling link 0262 raw data on spectrum utilization observations it has made to the Estimator/Predictor 0206, which predicts demand for any service of interest that may be affected. SSEs 0226 may also provide via a dedicated signaling link 0254 raw data on current or anticipated spectrum utilization to Predictor 0216, which also predicts demand for any service of interest that may be affected.

Overall Estimator 0220 processes all estimates and predictions and forms definitive and unambiguous service demand estimates for use by the SAE 0048. Estimates that are ambiguous are grouped and associated with a set of statistics, including without limitation: expected values and other central moments and estimated probability distributions. All estimates are sent together with any associated statistics together to the Resource-to-Demand Mapper 0214 within the SAE 0048.

The Resource-to-Demand Mapper 0214 processes deterministic and stochastic estimates of spectrum availability and service demand and determines possible mappings of available resources into service demands. Estimates are considered deterministic unless they are associated with a statistic, in which case they are considered stochastic.

The Optimizer 0212 evaluates possible mappings identified by the Resource-to-Demand Mapper 0214. The Optimizer 0212 implements evaluation by means which include without limitation: objective functions evaluating channel performance and overall network utility, accounting for factors including without limitation: the certainty of underlying data and current seller and buyer price specifications and mechanisms.

The Exchange/Synchronizer 0210 enables financial transactions in advance or in real time for resources that enable service demands processed by the SAE 0048. The Exchange/Synchronizer's functions include without limitation bid and ask price notification, maintenance of advance agreements (including without limitation Service Level Agreements), all associated billing functions, and maintenance of a common time base to coordinate market transactions and usage. The Exchange/Synchronizer 0210 also enables markets, including without limitation: (1) physical markets for resource commodities, e.g., "spot" markets, without regard to any specific service requirement; and (2) markets for derivatives, including without limitation options, futures, and futures options.

The Exchange/Synchronizer 0210 connects to SSEs 0226 via dedicated signaling link 0252 and to SDEs 0228 via dedicated signaling link 0260.

In an alternative embodiment of Apparatus A-3, the present invention embeds all of the functions of Allocator 0044 within a single station of the Sharing Operator. The single station could include without limitation: a base station or a mobile or fixed station.

## A.4. System of Interconnecting Different Wireless Networks

To implement most of the functions outlined in Sections A.1.–A.3., SDEs and SSEs must exchange certain information in a format that can be easily understood by all entities. However, not only are most wireless networks

offering one type of service not connected to wireless networks offering other types of services, many wireless networks offering the same type of service are not connected to each other. For example, broadcast television networks generally cannot communicate with CMRS networks. Moreover, one broadcast network generally cannot communicate with another broadcast network.

In general, each wireless service tends to have a unique set of technologies for communication among the nodes of such service. For example, broadcast television service has its own means of transporting signals from studio to antenna to receiver over spectrum in which it is exclusively licensed to operate. CMRS has its own means of transporting signals from public and private backbone networks to antenna to transceiver and in the reverse direction over spectrum in which it is exclusively licensed to operate. Broadcast television service utilizes modulation techniques and access systems that are unique to broadcast television service, while CMRS operators utilize modulation techniques and access systems that are unique to CMRS and could be even unique among different CMRS operators.

To determine the availability of any underutilized spectrum and enable SDEs to operate in such spectrum, there must exist some type of system that interconnects all those wireless networks wishing to make available or operate in underutilized spectrum.

The present invention includes a system of interconnecting different wireless networks to enable them to exchange information among each other. The present invention calls such a system an Inter-Wireless Network Signaling System (IWNSS), which comprises SDEs, SSEs, one or more Allocators 0044, and a number of monitoring stations attached to the networks of the SDEs and/or SSEs and/or acting autonomously under the control of the Allocator 0044 or some third party. The IWNSS includes links among some or all of the IWNSS nodes. These links could be wired or wireless. The IWNSS could utilize reserved or dedicated channels for transporting signaling information or it could share the same channels wireless networks utilize to transport information to and from their stations.

SDEs and SSEs could conceivably connect to each other directly. However, the large number of SDEs and SSEs makes such direct connections inefficient. It is more efficient for a large number of SDEs and a large number of SSEs each to make one connection to a centralized system like an Allocator 0044. For example, suppose that there are 20 SDEs and 20 SSEs. To connect each SDE to every SSE, there would have to be 400 (20 x 20) connections. However, if each SDE and SSE connected to one centralized system like an Allocator 0044, there could be as few as 40 connections (20 + 20).

In the preferred embodiment of the present invention, the IWNSS interconnects different wireless networks for the purpose of exchanging signaling information. However, the physical links can carry any kind of information, whether signaling or information or services wireless networks exchange with their stations.

In the preferred embodiment of the present invention, the IWNSS includes a set of network standards specifying how different wireless networks should exchange information for the purpose of signaling.

B. Requests for Service

B.1. Overall Method for Generating Service Request

The overall allocation process matches a supply of channel resources with demands for service by Sharing Operators. The present invention defines channel resources as comprising resources in time, frequency, code, space, and polarization that Incumbent Licensees make available (see Section C1). A service request consists of a number of parameters, including without limitation:

a. Time constraints, including without limitation: fixed start and stop times for which a channel is required.

b. Cost constraints, including without limitation: the maximum acceptable price which the Sharing Operator is willing to pay for a channel; and the form of market in which the Sharing Operator is willing to participate (e.g., auction, exchange).

c. Performance goals and/or requirements that the Sharing Operator either identifies explicitly or implies through some method of service differentiation. Service differentiation may be implemented through the following methods, including without limitation:

- Relative priority marking methods, such as IPv4 precedence marking
- Service marking methods, such as IPv4 TOS labeling
- Label switching methods, such as those employed in Frame Relay, ATM, and other Multi-Protocol Label Switching (MPLS) networks
- Integrated Services/RSVP methods, which employ signaling messages to differentiate services and reserve resources in advance.
- Static classification and forwarding policies, such as Service Level Agreements (SLA).
- Categorization by flow, such as that employed in the flow labeling employed in IPv6.

Quantified performance constraints and goals that are processed by the Allocator 0044 include without limitation:

i. Maximum required bit rate.
ii. Minimum guaranteed bit rate.
iii. Maximum required PDU size.
iv. Possible PDU sizes supported.
v. Minimum required bit error rate (BER).
vi. Minimum required PDU error rate.
vii. PDU delivery order requirements.
viii. Minimum required transfer delay.
ix. Traffic handling priority.
x. Allocation and retention priorities.

d. Station locations.

e. Station capabilities, including without limitation: explicit limitations station equipment may have in operating in the time, frequency, code, space, and polarization domains.

f. Flow metrics, including without limitation: total known or estimated flow size and known or estimated fraction of flow transmission completed. The present invention can measure flows at different OSI layers, including without limitation: frames at the MAC layer (Layer 2), packets at the Network layer (Layer 3), datagrams at the Transport layer (Layer 4), and messages at Session through Application layers (Layers 5-7).

g. Reliability requirements, including without limitation: channel availability and channel mean-time-between-failure (MTBF).

h. Statistical measures associated with service request information, including without limitation uncertainties in any estimated key service information such as station locations.

**METHOD B-1**: *Overall Method of Generating Service Requests.*

Method B-1 is a method that enables the SRE 0050 functions in Apparatus A-3.

a. Relationship to Overall Figure 1

The SRE 0050, which is a component of Allocator 0044, generates service requests. SRE 0050 processes information received by entities including without limitation: Brokers 0058, or SDEs 0052, 0054, or 0056.

b. Structure of the Block Diagram

Figure 4 shows a block diagram of the components involved in Method B-1.

i. Demand Validator/Estimator 2604 accepts raw service demand data, validates the information, and estimates the values of any missing data that will be required by the SAE 0048.

ii. Demand Estimator/Predictor 1110 Implements the same functions as the Demand Estimator but is also capable of predicting service demand based on historical and current service demand and spectrum utilization data.

iii. Demand Predictor 1106 predicts service demand based on historical and current spectrum utilization data.

iv. SDE Database 1104 stores historical service demand data.

v. SSE Database 1108 stores historical spectrum utilization data.

vi. MN Database 1112 stores historical service demand and spectrum utilization data.

vii. Overall Demand Estimator 1114 accepts multiple estimates and/or predictions and forms definitive service demand estimates.

c. Functional Relationships in Block Diagram

i. Demand Validator/Estimator 1102 accepts raw service demand data and stores service demand data in databases 2608.

ii. Demand Estimator/Predictor 1110 accepts raw service demand and spectrum utilization data and stores data in databases 1112.

iii. Demand Predictor 1106 accepts raw spectrum utilization data and stores spectrum utilization data in SSE Database 1108.

iv. Overall Demand Estimator 1114 processes estimates and predictions provided by Demand Validator/Estimator 2604, Demand Estimator/Predictor 1110, and Demand Predictors 1106. Overall Demand Estimator 1114 forms definitive and unambiguous service demand estimates for use by the SAE. Estimates that are ambiguous are grouped and associated with a set of statistics, including without limitation expected values and other central moments and estimated probability distributions.

d. Steps Executed in Method

Figure 5 shows a flow chart of the steps needed to execute Method B-1.

The SRE 0050 is hardware and software that is part of Allocator 0044 that identifies service requests in real-time and in advance and it processes and stores information about service requests and/or forecasted demand for service.

At Step 1000, SRE 0050 receives input from SSE and SDE and routes this data to Steps 1002, 1010, and 1016.

At Step 1002, Demand Validator/Estimator 1102 accepts raw demand data, validates the information, and estimates the values of any missing data that will be required by the SAE.

At Step 1004, Demand Validator/Estimator 1102 stores the service demand data in a database.

At Step 1006, Demand Validator/Estimator 1102 validates the service demand data.

At Step 1008, Demand Validator/Estimator 1102 estimates incomplete data and forwards this information to 1024.

At Step 1010, Demand Predictor 1106 receives spectrum utilization data from the SSE and predicts service demand based on historical and current service demand data and at Step 1012 stores this information.

At Step 1014, Demand Predictor 1106 predicts demand from available SSE history and passes this data to Step 1024.

At Step 1016, Demand Estimator/Predictor 1110 receives data from 1000 that forwards data from MN.

At Step 1018, along with 1020 and 1022, Demand Estimator/Predictor 1110 predicts service demand based on spectrum usage and service demand history and forwards this data to Step 1024.

At Step 1024, Overall Demand Estimator 1114 estimates demand from inputs from Steps 1008, 1014, 1020, and 1022.

At Step 1026, Overall Demand Estimator 1114 formats data from Steps 1024 and 1028 transmits the data for the SAE 0048.

e. Discussion

In the preferred embodiment of Method B-1, the SRE 0050 implements an object-oriented (see DEFINITION Section) approach to spectrum identification, as defined above. Such an embodiment includes without limitation the following features:

- Encapsulation of procedures and data. Encapsulation means that each object contains both the data and the procedures required to process the data. For example, the object described below is `ServiceRequestObject`. This object would include without limitation: variables related to the service request; equations, functions, or expressions describing the relationships among the variables; and the procedures required by the SAE to enable SAE functions which depend on or process SRE 0050 data.
- Messages supporting polymorphism across objects. Polymorphism means that each object can have a unique response to the same message.
- Classes that implement inheritance within class heirarchies. Inheritance means that one class of objects (e.g., a subclass) can be defined as a special case of a more general class (e.g., a superclass).

Examples of computer syntaxes that support the above features include without limitation: all versions of Smalltalk, C++, Java, Eiffel, Object COBOL, and recent versions of Ada. An example of a service request object (SRO) encoded with Java-like syntax which implements the above embodiment follows:

```
class ServiceRequestObject {

   \\ Local private variables
   private double start time;
   private double stop time;
   private PerformanceRequirement performance_requirement;
   private LocationObject location_1;
   private LocationObject location_2;
   private StationCapability capability_1;
   private StationCapability capability_2;
   private FlowMetrics flow metrics;
   private ReliabilityRequirements reliability requirement;

            .
            .
            .

   public ServiceRequestObject() {  \\ Constructor
            ...
   }
   \\ Methods providing access to private variables
   public double StartTime() {
   start_time;
   }
   public double StopTime() {
      stop time;
   }
   public Performance() {
      performance_requirement;
   }

            .
            .
            .

}
```

An instance of ServiceRequestObject is intended to hold all variables and methods ("methods" in software are different from the "Methods" described in the present invention) needed to: (1) maintain data related to a service request by a Sharing Operator; and (2) provide data and procedures needed by the SAE to allocate spectrum efficiently to Sharing Operators. The private, local variables contained within each instance of ServiceRequestObject include without limitation: all data associated with the time constraints, cost constraints, performance goals, station locations, station capabilities, flow metrics, and reliability constraints, as discussed above.

The present invention defines many of the private, local variables themselves in terms of objects rather than conventional data structures (e.g. double precision real variables, or integers). As an example, the present invention defines the private variable performance_requirement as an instance of the class PerformanceRequirement, which might be defined as follows:

```
class PerformanceRequirement {

   private double max_bit_rate;       \\ Maximum required bit rate
   private double min bit rate;       \\ Minimum required bit rate
   private int max pdu size;          \\ Maximum required PDU size
   private double min_ber;            \\ Minimum required BER
   private double min_delay;          \\ Minimum required transfer delay
```

```
          .
          .
          .

    public MaxBitRate() {
       max_bit_rate;
    }
    public MinBitRate() {
       min bit rate;
    }

          .
          .
          .

}
```

The program invokes constructor ServiceRequestObject() each time that the object is instantiated (i.e. created) and is designed to invoke all methods necessary to acquire the raw data necessary to the allocation process.

An example object could contain the variables and methods listed above, including without limitation:

- start_time: a local variable containing the time at which the service is required
- stop_time: a local variable containing the time at which the service will no longer be required
- location1, location2: Local variables that are instances of the class Location, which contain information about the geographical locations of the service requesters. LocationObject, for example, may be represented by an array of Cartesian coordinates in some geocentric coordinate system such as WGS-84 or in terms of a latitude, longitude, and altitude in some equatorial system of coordinates.
- station_capability1, station_capability2: Local variables that are instances of the class StationCapability, which contain information about the capabilities of the stations of the SDE. StationCapability, for example, may include without limitation information regarding the waveforms, power levels, and sensitivities of the transceiver at each station.
- flow_metrics: a local variable that is an instance of the class FlowMetrics, which contains information about the traffic flow associated with the service request. A FlowMetrics object, for example, may contain information regarding the total flow size and the percentage of the flow that remains to be transmitted.
- reliability_requirements: a local variable that is an instance of ReliabilityRequirements, which contains information about the service requester's reliability requirements. ReliabilityRequirements could include, for example, numerical values for availability (e.g. 99.9998), failure-in-time (FIT) rates, or mean-time-between-failure (MTBF).

The present invention defines a flow as a sequence of PDUs or their equivalent that have the same source, destination, and quality of service. The flow could be a sequence of PDUs with definite length (including without limitation files like .jpeg files) or a sequence of PDUs with indefinite length (including without limitation: a streaming broadcast or multicast).

The ServiceRequestObject serves as the parent (i.e. superclass) for other classes (i.e. subclasses) defining specific types of Sharing Operators. Subclasses may or may not overload or override the original ServiceRequestObject methods. For example, specific subclasses of the superclass ServiceRequestObject, IS95ServiceRequest, might be defined for service requests arising from IS-95 mobile operators using standard protocols in a non-standard frequency band. The present invention could define such an object with a unique constructor such that when the method

`Performance()` is invoked, the object could execute a procedure that translates IS95 standard requirements into the generic format defined by the `PerformanceRequirement` class.

In an alternative embodiment of Method B-1, the SAE 0048 would collect and process information about service requests using relational databases such as Microsoft Access or Personal Oracle and structured queries implemented through syntaxes such as the Data Definition and Data Manipulation Languages available within the Structured Query Language (SQL). A relational database could also coexist with and/or support an object-oriented implementation provided some application-layer bridge such as the Java Database Connectivity (JDBC) library is available.

## C. Identification of Underutilized Spectrum

### C.1. Channel Resource Definitions

Identification of underutilized spectrum requires a clear understanding of: (a) how the Incumbent Licensee controls access to the spectrum in which it is licensed to operate; and (b) how another wireless operator will control access to such spectrum if it shares that spectrum. The former is critical to the process of identifying underutilized spectrum and the latter is critical to allocating such spectrum.

Models for media access control in wired networks employing baseband digital signal transmission at the physical layer are well developed and well understood. Design and optimization of these networks are generally straightforward, since the physical layer connections consist of discrete segments with deterministic and unambiguous transmission properties that do not vary as a function of segment length or location. However, controlling how parties access wireless networks is more complex because of key differences in the physical layer of wireless networks:

- Electromagnetic signals propagate through unguided rather than guided media. Consequently, the design, optimization, and operation of wireless networks must consider variations in power density of signals propagating through network segments. In contrast, wired networks generally ignore such variations. Further, because signals in wireless networks are unguided, multi-access interference is unavoidable and ubiquitous, which must be considered in any channel resource allocation scheme.
- Two transmission segments of identical lengths in a wireless network could have very different transmission properties depending on their locations and timing of transmission.
- The transmission properties of wireless networks segments are stochastic, while those of wired network segments are deterministic.

Identification of underutilized spectrum requires determining, among other things, whether specific frequencies are available in specific geographical areas at specific times. The fact that stations attached to the Incumbent Licensee's network does not *per se* imply that the spectrum is fully utilized, since additional stations could possibly operate using the same spectrum without causing undue interference to the Incumbent Licensee's service. The degree to which the transmissions of the Sharing Operator will interfere with the transmissions of the Incumbent Licensee depends largely on the types of signals and power levels that the Incumbent Licensee and Sharing Operator are employing.

Utilization of spectrum by Incumbent Licensees can be quantified in terms of the extent to which Incumbent Licensees allocate available channel resources to stations operating within the radio frequency (RF) band of interest. Channel resources include not only the actual spectrum itself (i.e., frequency), but also resources in the time, code, space, and polarization domains.

a. <u>Frequency Resources</u>. Frequency domain resources include without limitation: a RF band that can be used to enable a communications channel between two nodes within a wireless network.

b. <u>Time Resources</u>. Time domain resources include without limitation: specific time slots in which messages, packets, frames, segments, or other transmission units can be transmitted from one station within the network to another station in the same network or another network. For example, TDMA systems employ time domain resources.

c. <u>Code Resources</u>. Code domain resources include all channel coding and modulation techniques that enable multiple messages to be transmitted simultaneously in time using a shared communication channel. The coding or modulation sequences include without limitation: orthogonal modulation techniques like those employed in CDMA with pseudo-noise (PN) coding or Orthogonal Frequency Division Multiplexing (OFDM); non-orthogonal basic modulation techniques like amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK); and spread spectrum multiple access techniques (SSMA) like Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS).

d. Space Resources. Spatial domain resources within wired networks typically consist of different physical routes for electromagnetic signals. Spatial domain resources within wireless networks must be treated differently because the electromagnetic signals employed at the physical layer are unguided rather than guided. While signal power densities in wired networks are confined within some well defined transmission path, signal power densities in wireless networks extend in all directions from the source. Therefore, allocation of spatial domain resources within wireless networks requires specifying desired and/or allowable interfering power densities at all points within the coverage areas of both the Incumbent Licensee's network and any wireless network wishing to share spectrum. The means for controlling power density include without limitation: power control and antenna beamforming using either fixed beam or smart antennas. Spatial domain resources may be allocated either statically, through the use of techniques including without limitation advance site and frequency planning, or dynamically through the use of techniques including without limitation real time power control and adaptive antenna beamforming.

e. Electromagnetic Field (Polarization) Resources. Propagating electromagnetic waves that are distant from the radiating source comprise a single electric field component and a single magnetic field component, each of which is orthogonal to the other. Because the two field components are orthogonal, separate transmitters may be colocated and share identical frequency, time, code, and space domain resources so long as they are generating electric and/or magnetic fields that are orthogonal to the electric and magnetic fields of the original transmitter. For example, separate transmitters could be colocated and share frequency, time, code, and space domain resources if one transmitter employed a vertically polarized antenna and another employed a horizontally polarized antenna, thus generating orthogonal electric and magnetic fields. This scheme is commonly classified as Polarization Division Multiple Access (PDMA). Electromagnetic field multi-access schemes such as PDMA are not generally practical in mobile wireless systems due to distortion of the field components by the propagation medium and due to difficulties in implementing stable receiving platforms. However, such systems are practical in a number of fixed wireless systems when the line-of-sight (LOS) between transmitter and receiver is unobstructed and multipath reflections are minimal.

A PDMA system may employ more than two orthogonal channels (e.g. a horizontally polarized and vertically polarized channel) if it can tolerate multiaccess interference (MAI). For example, an operator could implement a system with a horizontal channel, a vertical channel, and a 45-degree slant linearly polarized channel. The resulting carrier-to-interference ratio between the slant linear and vertical or horizontal channel in this case would be 3 dB, which is tolerable under some appropriate modulation and/or coding scheme.

C.2. Channel Resource Sharing Examples

In order to share a frequency resource with another operator, the Incumbent Licensee must be assured that the Sharing Operator will not also contend for any of the remaining resources employed within its active channels. The following examples illustrate some representative scenarios.

a. Example: Sharing with Incumbent Commercial Broadcasters. A wireless operator operating outside the protected coverage area 2202 (see DEFINITION Section) of incumbent commercial broadcast operators (see Figure 6) has essentially access to the following resources:

i. Frequency. The wireless operator can access the spectrum within the broadcasters' frequency channel.
ii. Time. The wireless operator can operate during all time periods.
iii. Code. The wireless operator can employ any modulation or coding scheme.
iv. Space. The wireless operator is restricted to control its effective radiated power (ERP) within certain limits in certain directions within its coverage area. The coverage area of the wireless operator must fall outside the protected coverage area of all broadcasters operating in any given frequency channel. The wireless operator can control ERP through the following ways, including without limitation: antenna pattern coverage, transmitter output power control, other techniques, or any combination of the foregoing.

v. Polarization. The wireless operator can employ all polarization resources.

b. Example: Sharing with a FDMA Wireless Operator. A wireless operator operating within the protected coverage area of another incumbent wireless operator employing Advanced Mobile Phone System (AMPS), which employs FDMA, has access to the following resources:

i. Frequency. The wireless operator can access the spectrum within a particular FM voice channel assigned by the Incumbent Licensee.
ii. Time. The wireless operator is restricted to operate during a certain time period specified by the Incumbent Licensee.
iii. Code. The wireless operator can employ any modulation or coding scheme.
iv. Space. The wireless operator can operate within the coverage area of the Incumbent Licensee.
v. Polarization. Because the wireless operator is not attempting to carry separate information on two orthogonal polarization states, it can employ all polarization resources.

c. Example: Sharing with a CDMA Wireless Operator with Conventional Sector Coverage. This example involves a wireless operator operating within the protected coverage area of another incumbent wireless operator employing IS-95 CDMA. IS-95 systems can continue to function with interference in both the downlink and uplink channels so long as the interference does not cause the carrier-to-interference+noise-ratio (CINR) to fall below some threshold value. When few users are operating within the protected coverage area of the Incumbent Licensee, other wireless operators could conceivably operate within the same spectrum provided that the resulting co-channel MAI is acceptable. The wireless operator has access to the following resources:

i. Frequency. The wireless operator can access the spectrum within a particular RF channel assigned by the Incumbent Licensee.
ii. Time. The wireless operator is restricted to operate during a certain time period specified by the Incumbent Licensee.
iii. Code. The wireless operator can employ any modulation or coding scheme so long as the power spectral density of the resulting signal is limited such that the resulting co-channel interference to the Incumbent Licensee's stations falls within some acceptable limit.
iv. Space. The wireless operator can operate within the coverage area of the Incumbent Licensee to the extent that the power control and modulation schemes employed do not produce undue co-channel interference, as described above.
v. Polarization. Because the wireless operator is not attempting to carry separate information on two orthogonal polarization states, it can employ all polarization resources.

d. Example: Sharing with a W-CDMA Wireless Operator with SDMA-enabled Sectors. W-CDMA will enable CDMA operators to increase significantly the number of users per sector through the use of multiple PN code offsets and other enabling technologies, such as Space Division Multiple Access (SDMA). Since SDMA/CDMA will permit the Incumbent Licensee to enable smaller and dynamically controlled angular sectors, other wireless operators must be careful in sharing the spectrum of the Incumbent Licensee. The wireless operator wishing to share the Incumbent Licensee's spectrum has access to the following resources:

i. Frequency. The wireless operator can access the spectrum within a particular RF channel assigned by the Incumbent Licensee.
ii. Time. The wireless operator is restricted to operate during a certain time period specified by the Incumbent Licensee.
iii. Code. The wireless operator can employ any modulation or coding scheme so long as the power spectral density of the resulting signal is limited such that the resulting co-channel interference to the Incumbent Licensee's stations falls within some acceptable limit.
iv. Space. The wireless operator can operate within coverage areas of the Incumbent Licensee that do not intersect those areas actively allocated to the Incumbent Licensee's users under SDMA. Like the previous example, power control and modulation schemes employed may not produce undue co-channel interference.

v. Polarization. Because the wireless operator is not attempting to carry separate information on two orthogonal polarization states, it can employ all polarization resources.

e. Example: Dynamic Allocation of PN Code Offsets Within a Single CDMA Network. In current IS-95 networks, the operator statically allocates PN code offsets to base stations. A base station within a CDMA sector typically employs a set of PN codes along with a fixed offset from codes employed by other CDMA base stations. Base stations operating at other cells and/or sectors may employ the same RF carrier frequency and PN code as long as they employ different PN offsets and satisfy other interference criteria. The availability of multiple PN offsets within W-CDMA may make dynamic allocation of PN offsets attractive. In this case, different base stations that are part of the network of the same Incumbent Licensee have access to the following resources:

i. Frequency. The sharing base stations can access the same RF carrier frequency.
ii. Time. The sharing base stations can operate in the same time period.
iii. Code. Each base station is allocated a unique PN code offset.
iv. Space. The base stations can operate in overlapping or co-located coverage areas.
v. Polarization. The base stations can employ all polarization resources.

f. Example: Sharing with a Fixed Wireless Local Multipoint Distribution Service (LMDS). LMDS operators typically operate at high microwave or millimeterwave frequency, often above the 28 GHz region. Because of the directivity that antennas are able to achieve practically at these frequencies, multipath reflections at receive stations are minimal. Further, receive and transmit stations generally have the same polarization states (e.g. horizontal, vertical, slant linear, or right-hand or left-hand circular). Provided that the Incumbent LMDS operator manages power densities and space and frequency resources so that the cross-polarization response of the incumbent LMDS operator remains within some acceptable limit, a second wireless operator could share the Incumbent Licensee's spectrum provided that the second wireless operator operated with a polarization orthogonal to that employed by the Incumbent Licensee. Given the constraints on cross-polarization response, the Sharing Operator would also likely operate a fixed, rather than mobile, wireless network. The Sharing Operator has access to the following resources:

i. Frequency. The wireless operator can access the spectrum within a particular RF channel assigned by the Incumbent Licensee.
ii. Time. The wireless operator can operate during any specific time period.
iii. Code. The wireless operator can employ any modulation or coding scheme so long as the power spectral density of the resulting signal is limited such that the resulting cross-polarization interference to the Incumbent's stations falls within some acceptable limit.
iv. Space. The wireless operator can operate within coverage areas of the Incumbent Licensee provided that it controls ERP in conjunction with modulation such that the resulting cross-polarization interference to the Incumbent's stations falls within some acceptable limit.
v. Polarization. The wireless operator is restricted to use of a polarization orthogonal to that employed by the Incumbent Licensee.

In general, an Incumbent Licensee is not fully utilizing the spectrum in which it is licensed to operate since the other associated channel resources, time, code, space, or polarization, may be available to some extent. As the above examples illustrate, even when operators are operating simultaneously within the same spectrum, other associated resources may be available such that both operators can construct viable communications channels. Whether the level of utilization of both the spectrum of interest and the other associated channel resources makes one or more channels available for use by other wireless operators will be addressed by the allocation system in Section D of the present invention.

C.3. Channel Resource Assignment Schemes Employed by Incumbent Licensees

The definition of methods that identify spectrum and other channel resources that are underutilized by Incumbent Licensees depends largely on how the Incumbent Licensees manage allocation of these resources to stations within their own networks. The procedures used by Incumbent Licensees to assign the channel resources described above

fall under one of three general categories: (a) fixed assignment (FA) control schemes; (b) demand assignment (DA) control schemes; and (c) random access (RA) control schemes. Each scheme provides unique challenges for entities outside the Incumbent Licensee's network attempting to identify whether or not the Incumbent Licensee is underutilizing available resources.

For example, a commercial broadcaster is a network that employs a FA control scheme to allocate a single frequency resource over a well-defined, limited geographical area. In the four-dimensional channel resource space, the Incumbent Licensee's frequency is essentially unoccupied in those locations outside the Incumbent Licensee's protected coverage area. Within the protected coverage area, certain modulation (code) resources can be considered unallocated (e.g. another operator could employ a FHSS signal at a certain power level while occupying the same time, frequency, space, and polarization as the Incumbent Licensee). An example of a network utilizing a DA control scheme would be an analog AMPS wireless system with 30 kHz channels, requested as needed by mobile stations within the network. Finally, an example of a RA control scheme would be a link between two stations operating in the unlicensed 2.4 GHz band.

C.4. Overall Method for Identifying Underutilized Spectrum

The present invention includes an overall method for identifying underutilized spectrum as well as specific methods targeted for use with incumbent networks employing specific channel resource assignment schemes to which the previous section refers. The present invention defines underutilized spectrum as spectrum that serves as the frequency resource for any given Incumbent Licensee's channel for which sufficient time, code, space, or polarization resources exist, such that another wireless operator could also use the same frequency resource to enable other channels on separate networks.

In general, this broad definition suggests that all spectrum could likely be considered underutilized, since there likely exists at least some small subset of time, code, space, and polarization resources that could be employed in a second channel. While the task of the allocation system will address the identification of *practical* subsets of channel resources, the task of the spectrum identification system is to identify the set of *available* channel resources within some predefined coverage area that could be associated with any particular frequency resource to form a new channel.

**METHOD C-1**: *Overall Method of Identifying Underutilized Spectrum.* In Method C-1, an Allocator 0044 monitors spectrum utilization by all wireless stations within a certain geographical coverage area that are operating in the RF bands of interest.

a. Relationship to Overall Method A-2

In Figure 1, the Allocator 0044 includes a component SIE 0046, which generates channel resource data. SIE 0046 processes information received by entities, including without limitation: Brokers 0058 or SSEs 0034, 0036, 0038, and 0040. SIE 0046 includes the components involved in Method C-1.

b. Structure of Block Diagram

Figure 7 shows a block diagram of the components involved in Method C-1.

The present invention notes that Method C-1 forms estimates of underutilized spectrum by obtaining data from both SSEs 0226 and SDEs 0228. Method C-1 evaluates service demand data because a wireless network with low service demand relative to its capacity should generally have more underutilized spectrum than a wireless network with high service demand relative to its capacity. Method C-1 evaluates service demand data from SDEs 0228 to forecast whether SDEs will have underutilized spectrum at later time periods, in which case the present invention would consider them as SSEs.

i. Supply Validator/Estimator 2102 accepts raw service demand data, validates the information, and estimates the values of any missing data that will be required by the SAE 0048.

ii. Supply Estimator/Predictor 2112 implements the same functions as the Supply Validator/Estimator 2102, but can also predict service demand based on historical and current service demand data.

iii. Supply Predictor 2106 predicts service demand based on historical and current spectrum utilization data.

iv. SSE Database 2104 stores historical service demand data.

v. SDE Database 2108 stores historical spectrum utilization data.

vi. Overall Supply Estimator 2110 accepts multiple estimates and/or predictions and forms definitive service demand estimates.

c. <u>Functional Relationships in Block Diagram</u>

i. <u>Supply Validator/Estimator 2102</u>

The Supply Validator/Estimator 2102 and Supply Estimator/Predictor 2112 accept raw channel resource data. Supply Validator/Estimator 2102 and Supply Estimator/Predictor 2112 store channel resource data in databases 2104 and 2114, respectively.

ii. <u>Supply Predictor 2106</u>

The Supply Predictor 2106 accepts raw service demand data and stores service demand data in SSE Database 2108.

iii. Supply Estimator/Predictor 2112

The Supply Estimator/Predictor 2112 implements the same functions as the Supply Validator/Estimator 2102 but is also capable of predicting service demand based on historical and current service demand data from MN database 2114.

iv. Overall Supply Estimator 2110

Overall Supply Estimator 2110 processes estimates and predictions provided by Supply Validator/Estimator 2102, Supply Estimator/Predictor 2112, and Supply Predictor 2106. Overall Supply Estimator 2110 forms definitive and unambiguous channel resource estimates for use by the SAE 0048. Overall Supply Estimator 2110 groups ambiguous estimates and associates them with a set of statistics, including without limitation: expected values and other central moments and estimated probability distributions.

After obtaining key channel resource information through these approaches, the Allocator 0044 determines and/or estimates, for any given band of frequencies, the state of channel resources that correspond to that band of frequencies. Such channel state information includes without limitation:

- Time for which the state estimate is valid.
- Location at which the state information is valid.
- Azimuthal (see DEFINITION Section) and/or elevation angles (see DEFINITION Section) over which the state information is valid.
- Estimated incident Poynting power densities (see DEFINITION Section) resulting from incumbent transmitters at a receiver at any given location and from any given direction.
- Estimated incident Poynting power densities resulting from unidentified sources, whether natural or man-made.
- Maximum allowed ERP at any given location and in any given direction.
- Limitations on coding (modulation) techniques that may be employed .

- Polarizations of signals received at all locations. The information gathered in spectrum identification must be sufficient so that a corresponding allocation method can configure resources to form usable shared frequency channels when the appropriate resources are available.

d. Steps Executed in Method

Figure 8 shows a flow chart of the steps needed to execute Method C-1.

A SIE 0046 is hardware and software that is part of the Allocator 0044 and that identifies underutilized spectrum in real-time and in advance, processes and stores information about underutilized spectrum, and/or forecasts supply of underutilized spectrum. Figure 8 describes the operation of the SIE as follows:

At Step 2000, SIE 0046 receives input from SSE 0226 and SDE 0228 and routes this data to Steps 2002, 2010, and 2016.

At Step 2002, Supply Validator/Estimator 2102 accepts raw utilization data and validates the information.

At Step 2004, Supply Validator/Estimator 2102 stores the information in a database.

At Step 2006, Supply Validator/Estimator 2102 validates the spectrum utilization data.

At Step 2008, Supply Validator/Estimator 2102 estimates incomplete data and forwards this information to Step 2024.

At Step 2010, Supply Predictor 2106 receives service demand data from the SDE 0228 and predicts service demand based on historical and current service demand data.

At Step 2012, Supply Predictor 2106 stores this information.

At Step 2014, Supply Predictor 2106 predicts spectrum utilization from available SSE history and passes this data to Step 2024.

At Step 2016, Supply Estimator/Predictor 2112 receives data from Step 2000 that in turn receives data from MN 0230.

At Step 2018, along with Steps 2020 and 2022, Supply Estimator/Predictor 2112 predicts spectrum utilization based on spectrum utilization and service demand history and forwards this data to Step 2024.

At Step 2024, Overall Supply Estimator 2110 estimates available resources from inputs at Steps 2008, 2014, 2020, and 2022.

At Step 2026, Overall Supply Estimator 2110 formats the data from Step 2024.

At Step 2028, Overall Supply Estimator 2110 transmits the data to the SAE 0048.

c. Discussion

In the preferred embodiment of Method C-1, the SIE 0046 implements the object-oriented approach introduced in Method B-1. An example of a channel resource object (CRO) encoded with Java-like syntax which implements the object-oriented embodiment is as follows:

```
class ChannelResourceObject {

    \\ Local private variables
    private double start_frequency;
    private double stop_frequency;
```

```
    private double start_time;
    private double stop_time;
    private PolarizationObject polarization;
    private LocationObject location;
    private AngleObject angle;

              .
              .
              .

    public ChannelResourceObject() { \\ Constructor
              ...
    }
    \\ Methods providing access to private variables
    public double StartFrequency() {
       start_frequency;
    }
    public double StopFrequency() {
       stop_frequency;
    }
    public double StartTime() {
       start_time;
    }
    public double StopTime() {
       stop_time;
    }
    public AngleObject Angle() {
       angle;
    }
    public LocationObject Location(){
       location;
    }

    \\ Methods providing data to allocator
    public PoyntingDensity IncidentPoyntingDensity(
       EmitterObject emitter) {
              ...
    }
    public ERP MaximumERP(ReceiverObject receivers
       ) {
              ...
    }
    public Modulation AllowedModulation() {
              ...
    }
              .
              .
              .
}
```

The present invention intends an instance of `ChannelResourceObject` to hold all variables and methods ("methods" in software are different from the "Methods" described in the present invention) needed to: (1) maintain data on channel resource allocation by the Incumbent Licensee; and (2) provide data needed by the Allocator 0044 to allocate spectrum efficiently to Sharing Operators.

An example object could contain without limitation the variables and methods listed above:

- start_frequency: a local variable containing the start frequency associated with the resource object.
- stop_frequency: a local variable containing the stop frequency associated with the resource object.
- start_time: a local variable containing the time at which the resource becomes available.
- stop time: a local variable containing the time at which the resource will no longer be available.
- polarization: a local variable that is an instance of the class PolarizationObject describing the polarization associated with the resource object. For example, the object may represent PolarizationObject as an array of ellipticities and eccentricities that define a polarization state.
- location: a local variable that is an instance of the class LocationObject, which contains information about the geographical location associated with the resource object. For example, the object may represent LocationObject as an array of Cartesian coordinates in some geocentric coordinate system such as WGS-84 or in terms of a latitude, longitude, and altitude in some equatorial system of coordinates.
- angle: a local variable that is an instance of the class AngleObject, which contains information about the angular sector associated with the resource object. For example, the object may represent AngleObject as a pair of azimuth and elevation angles.
- StartFrequency(): a method (procedure) that returns the value of the corresponding private (internal) variable start frequency.
- StopFrequency()(): a method (procedure) that returns the value of the corresponding private (internal) variable stop_frequency.
- StartTime()(): a method (procedure) that returns the value of the corresponding private (internal) variable start time.
- StopTime()(): a method (procedure) that returns the value of the corresponding private (internal) variable stop_time.
- Polarization(): a method (procedure) that returns the value of the corresponding private (internal) variable polarization.
- Location(): a method (procedure) that returns the value of the corresponding private (internal) variable location.
- IncidentPoyntingDensity(): a method (procedure) that calculates and returns the value of the power density in watts per square meter or some equivalent measure of all signals incident at the location and in the direction specified by location and angle at the specified polarization. IncidentPoyntingDensity() takes as an argument an object or objects of class EmitterObject, where an EmitterObject would contain all of the information required to compute the interferer incident power density, including without limitation: emitter location, polarization, output power, frequency, and antenna gain.
- MaximumERP(): a method (procedure) that calculates and returns the value of the maximum permitted effective radiated power (ERP) from the location and in the direction specified by location and angle at the specified polarization. IncidentPoyntingDensity() takes as an argument an object or objects of class ReceiverObject, where a ReceiverObject would contain all of the information required to compute the maximum permissible ERP, including without limitation: receiver location, polarization, frequency, antenna gain, and maximum tolerable interference level.
- AllowedModulation() a method (procedure) that identifies restrictions on modulation that can be used by an emitter at the location and in the directions specified by the resource object.

The ChannelResourceObject serves as the parent for other classes which may define for specific types of Incumbent Licensees and which may or may not overload or override the original ChannelResourceObject methods. The constructor method ChannelResourceObject() is invoked each time ChannelResourceObject is instantiated. Such method may require application of one type of method when collecting resource data from a fixed access channel such as a DTV broadcaster in an outlying area, where regulatory information may be adequate; and another type of method when

collecting resource data from within the geographical coverage area of a random access network, where data from distributed monitoring stations may be required.

In an alternative embodiment of Method C-1, an Allocator 0044 would collect information about identification of underutilized spectrum through using relational databases such as Microsoft Access or Personal Oracle and structured queries implemented through syntaxes such as the Data Definition and Data Manipulation Languages available within the Structured Query Language (SQL). A relational database could also coexist with and/or support an object-oriented implementation provided some application-layer bridge such as the Java Database Connectivity (JDBC) library is available.

C.5. Deterministic Methods for Identifying Underutilized Spectrum

The present invention includes deterministic methods for identifying underutilized spectrum in three generic types of channels.

a. Fixed Assigned Channels

The present invention defines fixed assigned (FA) channels as channels to which specific frequency, time, code, space, and polarization resources have been dedicated. Examples include without limitation analog and digital television broadcasters, AM and FM radio broadcasters, satellite broadcasters, and point-to-point microwave and millimeterwave backhaul links.

METHOD C-2: *Identification of Underutilized Spectrum in Fixed Assigned Channels.*

i. Relationship to Overall Method A-2

SIE 0046, which is a component of Allocator 0044, generates channel resource data associated with underutilized spectrum within FA channels. SIE 0046 processes information received by entities including without limitation: Brokers 0058, or SSEs 0034, 0036, 0038, and 0040.

ii. Structure of Block Diagram

Incumbent Licensees operate wireless networks with fixed assigned channels in protected coverage areas 2202 (see Figure 6). The protected coverage areas 2202 surround an area 2204 in which coverage by the incumbent networks is not protected. Two stations within another wireless network, 2206 and 2208, establish a link in which either or both station(s) operate within the frequency band assigned to the Incumbent Licensees.

iii. Functional Relationships in Block Diagram

SIE 0046 maintains a map 2302 of the area encompassing both the protected coverage areas 2202 and the unprotected coverage area 2204 (see Figures 6 and 9). In one embodiment, SIE 0046 divides the map 2302 into discrete grid squares 2304 (see Figure 10). SIE 0046 associates each grid square 2304 with a set of discrete angular sectors 2306 that correspond to angular coverage areas of any transmitter that would be located at the center of grid square 2304.

iv. Steps Executed in Method

Figures 11 and 12 show the steps executed in Method C-2.

The process begins at Step 2402 in Figure 11. At Step 2404, Method C-2 identifies the specific time intervals to be considered. At Step 2406, Method C-2 selects the first time step.

At Step 2406, Method C-2 identifies the specific frequency interval to be considered which corresponds to the time step of interest is identified. At Step 2412, Method C-2 selects the first frequency step within the current frequency interval.

At Step 2408, Method C-2 identifies the set of polarization states to be considered for the time and frequency step of interest. Method C-2 can convey polarization state information in a number of equivalent fashions including without limitation: phase and amplitude of each of two orthogonal components (including without limitation horizontal and vertical; right hand circular and left hand circular; or any combination of two orthogonal slant linear polarizations); polarization ellipticity and tilt (see DEFINITION Section); or latitude and longitude of the polarization when defined as a specific point on a Poincaré sphere (see DEFINITION Section). At Step 2414, Method C-2 identifies a specific polarization.

At Step 2416, Method C-2 identifies the spatial resource constraints associated with the combination of time, frequency, and polarization resources under consideration through a process that begins with Step 2500.

Figure 12 show steps 2500 through 2568.

At Step 2502, Method C-2 collects and retrieves all data regarding Incumbent Licensees. This data includes without limitation: information regarding the frequency allocations, times of operation, geographic locations, effective radiated powers, and protected coverage areas of Incumbent Licensees.

At Step 2504, the SIE 0046 defines discrete grid squares within the protected area 2202 and unprotected area 2204 (see Figure 6). The Supply Validator/Estimator 2102 chooses the dimensions of the grid squares such that the estimated power spectral density of emitted signals within the square is not expected to vary by more than some predetermined percentage. The resulting map will serve as a template for the remainder of the process.

At Step 2506, Method C-2 selects a specific Incumbent Licensee and creates a new map from the template defined in Step 2504.

At Step 2508, Method C-2 selects a grid square from the current map.

At Step 2510, the Supply Validator/Estimator 2102 estimates the power density in watts per square meter or any equivalent measure of signals emitted by each Incumbent transmitter within each grid square within the unprotected area 2204. The Supply Validator/Estimator 2102 may make these estimates using information available from the Incumbent Licensee in conjunction with standard propagation models, such as the Longley-Rice or Okumura-Hata models.

At Step 2512, Method C-2 makes a decision. If all grid squares within the current map have not been considered, Method C-2 executes Steps 2508 through 2512 until all grid squares have been considered.

If, at Step 2512, all grid squares have been considered, Method C-2 makes a decision at Step 2514. If all Incumbent Licensees of interest have not been considered, Method C-2 executes Steps 2506 through 2514 until all Incumbent Licensees have been considered.

If, at Step 2514, all Incumbent Licensees have been considered, Method C-2 executes Step 2515.

At Step 2515, Method C-2 creates a new map from the template defined in Step 2504.

At Step 2516, Method C-2 selects a grid square from the current map.

At Step 2518, Method C-2 segments each grid square into a number of angular sectors (See Figure 6). The resolution of each sector should be such that the gain of an antenna located within the grid square does not vary from one extreme of the sector to another by more than some predetermined percentage.

At Step 2520, Method C-2 selects an angular sector from the current grid square.

At Step 2530, the Supply Validator/Estimator 2102 estimates the total interference from Incumbent Licensees within each grid square from all directions based on the maps created for each Incumbent Licensee in Steps 2502 through 2514.

At Step 2532, Method C-2 makes a decision. If all angular sectors have not been considered for the current grid square, Method C-2 executes Steps 2520 through 2532 until all angular sectors have been considered.

If, at Step 2532, all angular sectors have been considered for the current grid square, Method C-2 executes Step 2534.

At Step 2534, Method C-2 makes a decision. If all grid squares on the current map have not been considered, Method C-2 executes Steps 2516 through 2534 until all squares have been considered.

If, at Step 2534, all grid squares within the current map have been considered, Method C-2 executes Step 2536.

At Step 2536, Method C-2 selects a new grid square within the current map.

At Step 2538, Method C-2 collects and/or retrieves all data regarding other sources of man-made or natural interference. This data includes without limitation: any other information available including without limitation calculations or prior measurements.

At Step 2540, Method C-2 makes a decision. If no new interference data is available for the current grid square, then Method C-2 executes Step 2536.

If, at Step 2540, new information regarding the current grid square is available, then Method C-2 executes Step 2542.

At Step 2542, Method C-2 selects an angular sector within the current grid square.

At Step 2544, Method C-2 makes a composite interference estimate from new information obtained in Step 2536 and from the Incumbent Licensee estimates made in Steps 2502 through 2514. Method C-2 makes the composite estimate by adding individual contributions accordingly. Interference that can be represented by additive white Gaussian noise (AWGN), for example, adds non-coherently (i.e., on a "10 log" or power basis), while interference that is fully correlated may add coherently (i.e., on a "20 log" or power basis).

At Step 2548, Method C-2 makes a decision. If all sectors within the current grid square have not been considered, then Method C-2 executes Steps 2542 through 2548 until all sectors have been considered.

If, at Step 2548, all sectors have been considered, Method C-2 makes a decision in Step 2550.

At Step 2550, if all grid squares have not been considered on the current map, Method C-2 executes Steps 2536 through 2550 until all grid squares have been considered.

If, at Step 2550, all grid squares have been considered, Method C-2 executes Step 2551.

At Step 2551, Method C-2 creates a new map from the template defined in Step 2504.

At Step 2552, Method C-2 selects a grid square from the current map.

At Step 2554, the Supply Validator/Estimator 2102 determines the maximum permitted undesired-to-desired signal ratios and/or interfering signal power density limits within each grid square within the protected coverage areas 2204 of the Incumbent Licensees. This information should be available from the

regulatory body responsible for licensing spectrum (Regulator), either directly or from regulations promulgated by the Regulator.

At Step 2556, Method C-2 makes a decision. If all grid squares have not been considered, Method C-2 executes Steps 2552 through 2556 until all grid squares have been considered.

If, at Step 2556, all grid squares have been considered, Method C-2 executes Step 2557.

At Step 2557, Method C-2 creates a new map.

At Step 2558, Method C-2 selects a new grid square from the current map.

At Step 2560, Method C-2 selects an angular sector from the current grid square.

At Step 2562, the Supply Validator/Estimator 2102 estimates the maximum ERP that would be allowed at a transmitter within the center of the grid square in order to maintain the maximum permitted undesired-to-desired signal ratios and/or interfering signal power density limits within each grid square within the protected coverage areas 1000 of the Incumbent Licensees. The maximum ERP is calculated using the formula:

$$ERP = 4\pi R^2/F^2(\mathbf{r}_S, \mathbf{r}_R)$$

where R is the radial distance in meters between the source and receiver; $\mathbf{r}_S$ and $\mathbf{r}_R$ represent the coordinates of the source and receiver in some system of geocentric coordinates (e.g. WGS-84); and $F(\mathbf{r}_S, \mathbf{r}_R)$ is the magnitude of the field propagation factor that applies to the path between the source and receiver. Method C-2 can determine the factor $F(\mathbf{r}_S, \mathbf{r}_R)$ from standard propagation models, such as the Longley-Rice or Okumura-Hata models.

At Step 2564, Method C-2 makes a decision. If all angular sectors have not been considered, then Method C-2 executes Steps 2560 through 2564 until all sectors have been considered.

If, at Step 2564, all angular sectors have been considered, Method C-2 executes Step 2566.

At Step 2566, Method C-2 makes a decision. If all grid squares have not been considered, Method C-2 executes Steps 2558 through 2566 until all grid squares have been considered.

At Step 2568, Method C-2 executes to Step 2418 (Figure 11).

At Step 2418, Method C-2 evaluates all modulation constraints that may be placed on a Sharing Operator.

At Step 2420, the Overall Supply Estimator 2110 creates a channel resource data structure, such as the Channel Resource Object described in the preferred embodiment.

At Step 2422, Method C-2 sends channel resource data to the SAE 0048.

At Step 2424, Method C-2 makes a decision. If all polarizations have been considered for the current time and frequency slot, Method C-2 executes Step 2426. Otherwise, Method C-2 executes Step 2414.

At Step 2426, Method C-2 makes a decision. If all frequency slots have been considered for the current time slot, Method C-2 executes Step 2428. Otherwise, Method C-2 executes Step 2412.

At Step 2428, Method C-2 makes a decision. If all time slots have been considered for the current time slot, Method C-2 exits at Step 2430. Otherwise, Method C-2 executes Step 2410.

b. Demand Assigned Channels

The present invention defines demand assigned (DA) channels as channels employed in networks where stations demand resources through some dedicated signaling channel from certain network entities responsible for allocating time, frequency, code, space, and polarization resources. Examples of networks employing DA channels include without limitation: CMRS operators employing FDMA, TDMA, GSM, or CDMA transmission protocols; land mobile radio (LMR) systems employing trunked FM or single sideband (SSB) channels; and wireless systems employing resource auction multiple access (RAMA) algorithms.

METHOD C-3: *Identification of Underutilized Spectrum in Demand Assigned Channels.*

i. Relationship to Overall Method A-2

SIE 0046, which is a component of Allocator 0044, generates channel resource data associated with underutilized spectrum within DA channels. SIE 0046 processes information received by entities including without limitation: Brokers 0058, or SSEs 0034, 0036, 0038, and 0040.

ii. Structure of Block Diagram

Figure 13 shows a network employing DA channels that is operated by an Incumbent Licensee within coverage area 2602. Stations 2610 within the incumbent network demand channel resources from some network entity 2604 (e.g., a base station) using dedicated signaling link 2606. The network entity 2604 assigns channel resources to enable an information transmission link 2606.

iii. Functional Relationships in Block Diagram

Network entity 2604 notifies Exchange 2612 about the disposition of channel resources, including spectrum, at the disposal of the network.

Stations 2614 are within different coverage areas, but are part of the Incumbent Licensee's service and share some of the same channel resources as the network to which stations 2610 and 2604 are attached.

iv. Steps for Executing Method

The steps for executing Method C-3 are similar to the steps for executing Method C-2. The steps listed below reflect the different steps necessary to accommodate the identification of demand assigned channels.

(1) The Exchange 2612 implements Method C-2 in order to identify resource configurations under which the sharing network and incumbent network would operate simultaneously with tolerable levels of MAI.

(2) The Exchange 2612 next identifies but does not store resource configurations under which the sharing network would operate with tolerable levels of MAI in remote coverage areas 2614, without regard to interference to the nearby coverage area. Method C-3 implements this step through the relevant steps of Method C-2.

(3) The Exchange 2612 receives from incumbent network entity 2604 the times at which the configurations in Step 2 are available. For example, these times could represent times within coverage area 2602 at which certain FDMA channels are available or times during which additional non-coherent MAI could be tolerated within a CDMA channel.

(4) The Exchange 2612 associates the time intervals determined in Step 3 with the resource configurations determined in Step 2 to build complete CROs.

(5) The Exchange 2612 builds and maintains the valid CROs.

c. Random Access Channels

The present invention defines random access (RA) channels as those channels employed in networks where stations contend for access to the channel using methods that may lead to overlapping or colliding simultaneous transmissions, which in turn may require stations to retransmit. Different types of random access schemes can include without limitation: fixed schemes in which stations transmit without coordinating access with other stations; or adaptive channel-sensing schemes in which stations first sense the channel to gain channel state information. Examples of networks that employ fixed RA schemes include without limitation: networks that employ ALOHA, slotted ALOHA, and group random access protocols. Examples of networks that employ adaptive channel-sensing RA schemes include without limitation: networks that employ persistent and non-persistent CSMA, CSMA with collision detection (CSMA/CD), packet reservation multiple access (PRMA), and busy tone multiple access (BTMA) protocols.

The present invention can consider a channel a RA channel even if stations occupying the channel are not employing an RA protocol, but are operating within an independent, uncoordinated network. Examples include without limitation networks which implement open and proprietary fixed and/or demand assignment schemes within unlicensed frequency bands. Although the individual networks may not implement random access schemes, the network as a whole is accessing the channel in a random fashion from the perspective of any other service on the channel.

Because RA networks do not coordinate channel access decisions, deterministic identification of underutilized spectrum in advance is impractical. However, statistical techniques such as the method proposed below can provide a degree of advance identification. Further, because random access networks frequently defy well-defined coverage boundaries, identification of resources through information provided by some entity central to the incumbent network is also impractical. The lack of clear boundaries and central allocating authorities requires a distributed rather than centralized method for identifying underutilized spectrum.

**METHOD C-4**: *Identification of Underutilized Spectrum in Random Access Channels.*

i. Relationship to Overall Method A-2

SIE 2656 (equivalent to SIE 0046), which is a component of Allocator 0044, generates channel resource data associated with underutilized spectrum within RA channels. SIE 2656 processes information received by entities including without limitation: Brokers 0058, or SSEs 0034, 0036, 0038, and 0040.

ii. Structure of Block Diagram

Figure 14 shows a network employing RA channels that is operating within area 2652. Area 2652 may or may not be a protected coverage area, whether by authority of the Regulator or by agreements with networks operating within area 2652.

iii. Functional Relationships in Block Diagram

Stations 2654 form a network of interference monitoring stations which may be operating entirely outside area 2652 (as shown) or entirely or partially within area 2652. All stations 2654 within the network are connected to a SIE 2656 via dedicated signaling links 2658. The network monitoring stations 2654 may also be eventual members of the network that will contend with the RA network for resources, in which case the interference monitoring functions required are embedded within the hardware of the stations.

iv. Steps for Executing Method

The steps for executing Method C-4 are similar to the steps for executing Method C-2. The steps listed below reflect the different steps necessary to accommodate the identification of random assigned channels.

(1) The SIE 2656 implements Step 2504 of Method C-2 and creates a detailed map of all relevant coverage areas.

(2) If area 2652 is considered a protected coverage area, the SIE 2656 first identifies and stores resource configurations under which the sharing network and incumbent network would operate simultaneously with tolerable levels of MAI to the incumbent network within all coverage areas under consideration (2602 and 2614). Method C-4 implements this step through the relevant steps of Method C-2.

(3) If area 2652 is not considered a protected coverage area, the SIE 2656 monitors interference reports from monitoring stations 2654. Based on the interference reports received, the SIE 2656 estimates through interpolation or some other means the interference power density within each grid square of the map defined in Step 1. Finally, the SIE 2656 creates and stores RCRs for each grid square and each frequency channel under consideration that include the interference estimates gathered.

v. Discussion

The present invention applies Method C-4 to Unlicensed Channels described in Section A.1.b.iii.(3)(c). The present invention assumes that Regulators may permit Sharing Operators to operate in those channels not licensed to any Incumbent Licensee, e.g., unprotected coverage areas of licensed television broadcasters or any RF band not licensed by Regulators to any Incumbent Licensee regardless of geographical area. The present invention treats Unlicensed Channels as RA channels. Because no Incumbent Licensee can control access to Unlicensed Channels, any Sharing Operator must access Unlicensed Channels with the expectation that other Sharing Operators may also try to access such Channels.

C.6. Statistical Methods for Identifying Underutilized Spectrum

a. Stochastic Channel Resource Objects

In the above methods, the present invention identifies the time resource in the following deterministic ways, including without limitation:

i. From static allocation information associated with fixed assignment channels.
ii. From dynamic allocation information provided by Incumbent Licensees operating demand assignment channels.
iii. From an implicit claim on the time resource employed in random access channels.

In each case, the methods considered the resources to be available with probability $P_a = 1$ throughout the duration defined by the start and stop times specified in the associated CRO. In general, resource availability may not be deterministic, but, in fact, may be a stochastic process (i.e., a process that varies in time in a non-deterministic fashion) that is also possibly non-stationary (i.e., the statistics of the process themselves vary with time).

When allocations are based on instantaneous short-term observations of a stochastic process, chaotic network behavior could result. In such cases, the present invention must make an accommodation for estimation and prediction in the general procedure for creating CROs.

To accommodate stochastic resource availability, the present invention considers an additional dimension of probability in the creation of channel resource objects. While in the deterministic case, a single object described the availability of frequency, code, space, and polarization resources over some specified time interval, the present invention defines a *stochastic channel resource object* (SCRO) as an object that will provide probabilities with which each instance of a particular deterministic channel resource object will occur over the specified time interval. The inclusion of raw probability estimates rather than estimates of some other statistic such as expected value will provide the Allocator 0044 with the means to allocate more efficiently channel resources jointly among multiple stations when the resource availabilities are stochastic processes.

**METHOD C-5**: *Overall Method for Identifying Underutilized Spectrum Under Stochastic Channel Resource Availability*

The relationship of Method C-5 to Overall Method A-2, the structure of the block diagram, and functional relationships in the block diagram are identical to those listed under Method C-1.

i. Steps for Executing Method

The SIE 0046 implements Methods C-1 through C-4 to identify underutilized spectrum within some time interval in fixed assignment, demand assignment, and/or random access channels operated by other Sharing Operators or Incumbent Licensees. Based on resource availability histories, predictions, or any *a priori* information available regarding future disposition of channel resources, the SIE 0046: (a) defines a discrete set of available resource configurations (frequency, code, space, polarization) that may occur within the time interval specified; and (b) estimates the discrete probability mass function over the space of potential channel resource configurations.

The preferred embodiment of Method C-5 implements a new channel resource object known as a *stochastic channel resource object* (SCRO). A SCRO consists of a CRO associated with some probability. Method C-5 can implement the space of possible SCROs as an array. An example of one possible SCRO implementation encoded with Java-like syntax is as follows:

```
class StochasticChannelResourceObject {

        private ChannelResourceObject cro;
        private double prob;

                        .
                        .
                        .

        public StochasticChannelResourceObject(
              ChannelResourceObject c, double p) {
              cro - c;
              prob - p;
        }

        public Probability() {
              prob;
        }
}
```

C.7. Identification of Channel Resources in Advance

The identification of channel resources in advance requires either direct advance notification by resource owners (Incumbent Licensees) or some other source of information from which resource availability the present invention can infer in either a deterministic or probabilistic fashion.

When channel resources are available in advance, they are available either because: (1) the Incumbent Licensee has statically and definitively scheduled their availability; or (2) some unscheduled event or lack thereof has rendered resources available or unavailable. The Incumbent Licensee can directly transmit to the SIE 0046 or the Allocator 0044 infers via some other means information regarding the availability of resources.

Figure 20-2 shows the means by which information reaches the Allocator 0044. Figure 20-2 shows a particular embodiment of the Allocator 0044 called a "Spectrum Router".

In the overall spectrum sharing paradigm, the present invention considers two parallel networks: an Information Transmission (IT) network and a Signaling network.

The IT network operates simultaneously at multiple layers. In Figure 21, for example, suppose that a wireless network establishes an http connection between nodes 1 and 5, where node 1 is a multimedia server and node 5 is a web-enabled mobile station. Further suppose that nodes 1 and 5 connect through a proxy server at node 2. Layer C in the figure illustrates the OSI Application Layer (Layer 7) connections.

Suppose that the multimedia server (1), proxy server (2), and mobile station (5) all connect via an IP network that includes a router (3) at the Mobile Switching Center (MSC). Layer B in the figure illustrates the OSI Network Layer (Layer 3) connections.

Finally, suppose that the MSC router (3) connects to the mobile station (5) via some Base Transceiver Station (BTS) (4) over the wireless operator's standard air interface. The physical connections among the other nodes are via some other wired network protocol. Layer A in the figure illustrates the OSI Physical and Data Link (Layers 1-2) connections.

Wireless networks are unique in that they are essentially broadcast networks at the physical layer, whether intentionally or not. The figure illustrates this concept with the multiple arrows originating at the BTS (4) in the figure's Layer A depiction. The figure assumes some other station (6) to be monitoring transmissions of the BTS (4) over its air interface, where the station may or may not be able to extract useful higher layer information from the transmissions.

The second column illustrates what the present invention refers to as the Spectrum Router Signaling Network (SRSN). The SRSN consists of the Spectrum Router itself, various monitoring stations, and (not shown) other entities with which the Spectrum Router communicates to enable other functions of the overall Efficient Spectrum system.

The figure illustrates how each layer of the IT network may have one or more monitoring stations associated with individual nodes. For example, at Layer A, the BTS (4) and mobile station (5) may include functions that: (1) monitor various channel resources, including without limitation: modulation, incident power density, and polarization; and (2) tracks their usage over time and frequency. Autonomous nodes such as (6) may also provide these functions. At Layer B, the MSC router (3) provides key packet information collected from IP transmissions, including without limitation packet size, packet source address, packet destination address, and packet flow category. Finally, at Layer C, the proxy server (2) provides additional key flow information from the application layer connections between 1 and 5, including without limitation: message sizes and percentages of messages sent or remaining.

The present invention may implement the Signaling Network as a separate network outside the IT Network (e.g., like SS7 in the PSTN) or by embedding functions within the IT Network (e.g., similar to IP and RSVP).

This model of the Spectrum Router monitoring functions is extremely general. In general, the present invention enables spectrum supply monitoring functions by any arbitrary monitoring node within the SRSN at the lowest layers and enables demand monitoring functions at any arbitrary monitoring node at any other layer within the SRSN, including without limitation: network, transport, session, and application. Furthermore, the simultaneous operation of various monitoring nodes at multiple layers permits the present invention to associate demand behavior with supply behavior and vice versa. The overall system, through learning or predefined algorithms, can make predictions of future supply of underutilized spectrum and/or future demand for service through real-time and/or historical observations from all monitoring nodes within the SRSN.

Figure 21 illustrates interfaces between the layers of an Information Transmission network and the SRSN. In fact, one or more Incumbent Signaling Networks (ISNs) may also be associated with the Information Transmission network. The present invention defines ISNs a network separate from the IT network employed to establish, maintain, and terminate connections within the IT network. ISNs focus on signaling information required by a particular wireless network. In contrast, the SRSN focuses on signaling information required to interconnect different wireless networks. Figure 22 shows links between the multimedia server (1) and the proxy server (2) and one ISN that may, for example, implement the advance resource reservation function required under RSVP provisions of the Internet Protocol (IP) operating at Layer B. A second ISN associated with Layer B may implement the control functions required at the mobile station, BTS, and MSC. The ISNs may offer one or more POPs (or

points-of-presence) for the SRSN, as Figure 22 shows by connection between ISN nodes and the Spectrum Router node.

**METHOD C-6**: *Overall Method for Identifying Underutilized Spectrum in Advance.*

The overall method for identifying underutilized spectrum in advance implements the functions required to identify frequency, time, code, space, and polarization resources which are expected to become available on either a scheduled or unscheduled basis. Method C-6 utilizes POPs at both the Signaling Network and Information Transmission Network of Incumbent Licensees.

i. Relationship to Overall Method A-2

Method C-6 is the overall method utilized by SIE 0046 to identify underutilized spectrum in advance.

ii. Structure of Block Diagram

A SRSN includes a number of Monitoring Nodes as well as Allocator 0044. One or more stations operated by a particular wireless operator participates in a multilayer Information Transmission Network (ITN), where the participating stations are nodes within the ITN.

Incumbent Licensees or other entities with nodes participating in the ITN may participate in one or more ISNs.

iii. Functional Relationships in Block Diagram

Monitoring nodes within the SRSN maintain POPs at certain nodes within both the ITN and ISN. ITN nodes provide the Spectrum Router with layer-specific information including without limitation: the layer's service user data, service provider data, and any other data available from the layer Service Access Point (SAP) (see DEFINITION Section).

ISN nodes provide the Spectrum Router with information regarding multi-access resources that an Incumbent Licensee has, is, or will allocate to a particular ISN connection. Information could include without limitation that information a mobile telephony control channel would provide regarding channel resource assignments, including without limitation: time, frequency, code, space, and polarization; message transfer, signaling connection, telephone usage, ISDN usage, or transactions capabilities information that a Signaling System 7 (SS7) network would provide; and/or information provided within the Resource Reservation Protocol (RSVP) reservation request, path, error and confirmation, and teardown messages.

iv. Steps for Executing Method

SIE 0046 receives advance spectrum utilization data (OSI Layer 1) from SSEs via SSE Monitoring Nodes within the SRSN and implements Steps 2002 through 2008 of Method C-1.

SIE 0046 receives advance service demand data (OSI Layers 2-7) from SDEs via SSE Monitoring Nodes within the SRSN and implements Steps 2010-2014 of Method C-1.

SIE 0046 receives advance service demand data (OSI Layers 2-7) and advance spectrum utilization data (OSI Layer 1) from other Monitoring Nodes within the SRSN and implements Steps 2016 through 2022 of Method C-1.

SIE 0046 implements the remaining steps of Method C-1 (Steps 2024-2028).

v. Discussion

In the preferred embodiment, the SRSN transports information about service requests identified in real-time and/or in advance and underutilized spectrum identified in real-time and/or in advance. In an alternative

embodiment, the SRSN can transport not only signaling information, but also actual information or content transmitted by wireless networks.

C.8. Identification of Any and All Underutilized Spectrum

Section C has described a variety of methods for identifying underutilized spectrum in real-time and in advance. In general, the present invention classifies all spectrum utilization by Incumbent Licensees in terms of how Incumbent Licensees utilize frequency, time, code, space, and polarization resources. The present invention defines a channel resource as a unique set of frequency, time, code, space, and polarization resources. The present invention classifies underutilized spectrum as all channel resources not utilized by an Incumbent Licensee. The present invention notes explicitly that underutilized spectrum can include channel resources in frequency bands licensed to Incumbent Licensees or frequency bands not licensed to any entity.

While the present invention proposes several methods for identifying underutilized spectrum, it notes that there may exist other methods for such identification. Regardless of how underutilized spectrum is identified or what method may be utilized, the present invention utilizes all such underutilized spectrum for the purpose of enabling any, some, or all SDEs 0228 to operate in such underutilized spectrum. The present invention utilizes any combination of frequency, time, code, space, and polarization resources not utilized by an Incumbent Licensee.

## D. Allocation of Underutilized Spectrum to Requests for Service

### D.1. Spectrum Allocation Engine

Allocation of channel resources requires a method that: (a) interprets service demand data from one or more parties to derive channel resource requirements; (b) identifies partitions of available resources which would fulfill the requirements of SDEs 0228; (c) enables the free-market exchange of resources between buying and selling parties; and (d) suggests alternative partitions and/or additional resource offerings to suppliers when the current supply cannot meet demand requirements.

Although one can draw an analogy between the market exchange function of a channel resource allocator and a commodities exchange, the analogy is not perfect. Within a commodities exchange, buyers bid for and sellers offer a single good. The buyer's intended use of the good is not relevant. Although the exchange could conceivably implement a method for analyzing the buyer's particular use and derive the quantity of the commodity the buyer would need, this process would add no value for the buyer or the seller.

As discussed previously, spectrum by itself is not a useful commodity unless additional associated resources - time, code, space, and polarization - are adequate. Because the combination of resources that will support a particular service demand is not, in general, unique, a particular buyer's choice of bid is ambiguous. For example, the Shannon capacity theorem states that the capacity of a particular communications channel in bits per second (bps) depends on the bandwidth of the channel in Hertz (Hz) and on the signal-to-noise ratio at the receiver:

$$C = B \log_2(1+S/N)$$

If a particular service demand requires 1 Mbps capacity, the demand could be fulfilled by any channel for which:

$$B = 1/(\log_2(1+S/N))$$

could fulfill such demand (e.g., a 1 MHz channel with a signal-to-noise ratio of 1, a 500 kHz channel with a signal-to-noise ratio of 3, etc.).

The channel resource allocation method defined in the present invention adds value for both buyer and seller. It adds value for the buyer by translating service requirements into unambiguous resource requirements. It adds value for the seller by ensuring that all resource dimensions are considered in the allocation process, thereby maximizing spectrum utilization.

### D.2. Model for Channel Resource Allocation

The present invention defines the channel resource allocation problem as follows:

Some number of Incumbent Licensees serve as the ultimate suppliers of channel resources, where the present invention defines a channel resource as some set of time, frequency, code, space, and polarization resources, as defined above.

In the channel resource allocation problem, one or more SSEs 0226 offer a number of channel resource sets, or parcels, where the number of parcels offered may vary with time. The SSEs 0226 offering these resources can include without limitation those entities listed in the DEFINITION Section under "SSEs." The present invention denotes the time-varying offered resource supply by **R(t)**. The present invention associates with the offered supply **R(t)** a set of pricing specifications, **A(t)**, which includes without limitation such information as the minimum asking price and preferred exchange method (e.g. auction).

At the same time that SSEs 0226 are offering channel resources, SDEs 0228 are presenting a number of service demands, where the demands may vary with time. The SDEs 0228 presenting these demands can include without limitation those entities listed in the DEFINITION Section under "SDEs." The present invention denotes the time-varying set of service demands by **S(t)**. The present invention associates with demand set **S(t)** a set of bidding

specifications, **B(t)**, which includes without limitation such information as the maximum bid price and type of order (e.g., market or limit).

For any given **R(t)** and **S(t)**, the set of all possible ordered pairs $(R_i,S_j)$ of resource parcels with service demands is given by:

$$\mathbf{M} = \mathbf{R(t)} \times \mathbf{S(t)} = \{ (R_1,S_1), (R_1,S_2), \ldots, (R_i,S_j), \ldots, (R_{NR}, S_{NS}) \}$$

where $N_R$ is the number of available resource parcels and $N_S$ is the number of pending service requests. .

The *power set* of **M**, P[**M**], consists of all possible subsets of ordered pairs within **M**, including the empty set, $\phi$. Each subset of **M** represents a potential set of channel mappings of some or all of the available resources **R(t)** into some or all of the pending service demands **S(t)**.

As an example, consider the following scenario:

> The resources associated with a particular AMPS channel are available at time t and labeled as parcel $R_1$. At the same time, the resources associated with a particular CDMA channel are also available. The example denotes the resource as parcel $R_2$. Furthermore, a CDMA operator needing an additional voice channel that would be defined using standard CDMA protocol presents a demand for service at the same time, t. The example denotes the service demand as $S_1$. In this case:
>
> $$\mathbf{R(t)} = \{ R_1, R_2 \}$$
>
> $$\mathbf{S(t)} = \{ S_1 \}$$
>
> The set of all possible pairings of resource parcels with the pending service request is:
>
> $$\mathbf{M} = \{ (R_1,S_1), (R_2,S_1) \}$$
>
> The first pair, $(R_1,S_1)$, implies that the AMPS resource is paired with the CDMA service request. The second pair, $(R_2,S_1)$, implies that the CDMA resource is paired with the CDMA service request.
>
> The power set of **M** - the set of all possible subsets of **M** - is:
>
> $$P[\mathbf{M}] = \{ \phi, \{ (R_1,S_1) \}, \{ (R_2,S_1) \}, \{ (R_1,S_1), (R_2,S_1) \} \}$$
>
> The interpretation for each element is as follows:
>
> $\phi$: Corresponds to the case where no resources are assigned and the service request is left unfulfilled.
> $\{ (R_1,S_1) \}$: Corresponds to the case where the AMPS resource is paired with the CDMA service request.
> $\{ (R_2,S_1) \}$: Corresponds to the case where the CDMA resource is paired with the CDMA service request
> $\{ (R_1,S_1), (R_2,S_1) \}$: Corresponds to the case where both resources are paired with the CDMA service request.

In the above example, the present invention makes no attempt to determine which of the possible mappings within P[**M**] was preferred - the present invention simply enumerates potential mappings. To determine which of the possible mappings is preferred, the present invention defines a series of objective functions:

a. A performance objective function, $\Psi_p$ ($\mathbf{M}_i'$) is defined as a function that produces some numerical output that depends solely on the pairings $(R_i,S_j)$ within $\mathbf{M}_i'$ and nothing else, where $\mathbf{M}_i'$ is defined as the i-th subset of **M** within in P[**M**] that is to be considered.

b. A utility objective function $\Psi_u$ ( $\mathbf{M}_i'$ ; $\mathbf{A}_i'$,$\mathbf{B}_i'$ ) is defined as a function that produces some numerical output that depends not only on $\mathbf{M}_i'$, but also on the bid and ask price specifications $\mathbf{A}_i'$ and $\mathbf{B}_i'$ that correspond to the

elements of S and R, respectively, within $M_i'$. The sets formed by these elements are denoted $S_i'$ and $R_i'$, respectively.

c. An overall objective function is denoted by $\Psi(\Psi_p, \Psi_u)$.

D.3. General SAE Algorithms

The present invention defines a number of general algorithms for the SAE 0048 below. These algorithms form the basis for a number of methods to be defined later:

a. Resource Partitioning: Identify useful mappings, M', of R(t), the channel resource supply into service demands S(t), as defined above.
b. Evaluation: Evaluate the performance and utility of each mapping $M_i'$ identified.
c. Free-Market Exchange: Enable the free-market exchange of resources between suppliers and demanders in a manner which meets the pricing specifications within **A(t)** and the bidding specifications within **B(t)**.

D.4. Overall Method of Channel Resource Allocation

a. Description of Overall Method of Channel Resource Allocation

**METHOD D-1**: *Overall Method of Channel Resource Allocation in Response to Service Requests.* Method D-1 is a method for pairing available channel resource parcels identified by the SIE 0046 with service requests identified by the SRE 0050.

i. Relationship to Overall Method A-2

Method D-1 implements the function of the SAE 0048 within the Allocator 0044. SDE 0228 may be Sharing Operators such as 0052 or 0056. SSE 0226 may be Incumbent Licensees such as 0034 or 0038.

ii. Structure of Block Diagram

Figure 15 shows the entities required to implement the channel resource allocation process. A Service Request Queue 3030 stores pending service requests provided by the Service Request Engine 0050. A Resource Database 3010 stores data on all available resources provided by the SIE 046. A Channel Mapper 3016 identifies possible mappings of available resources to service requests. A Network Performance Evaluator 3014 estimates, predicts, and/or evaluates the performance of a given network according to some predefined judgment criteria, where the network is defined by a resource partition, a service partition, and the relation between the two partitions. A Network Utility Evaluator 3008 estimates, predicts, and/or evaluates the utility of a given network according to some predefined judgment criteria. A Network Optimizer 3006 decides whether a given network is acceptable or if additional operations need to be performed. An Exchange 3004 processes ask and bid price specifications associated with some set of available resources and service requests. A Channel Allocator 3002 manages the eventual assignment and management of available resources and service demands. A Billing Application 3026 manages bill processing. A Billing Database 3028 stores bill processing output. A Network Synchronizer 3022 ensures that two or more SDEs 0228 or SSEs 0226 have access to the same reference clock.

iii. Functional Relationships in Block Diagram

The Channel Mapper 3016 reads as a set some or all of the service requests within the Service Request Queue 3030 and loads available channel resource data from Resource Database 3010.

The number of requests read from the Queue 3030 may vary with implementation. If the Allocator 0044 implements a First Come First Serve (FCFS) allocation algorithm, for example, the algorithm will read or process only one request at a time. If the Allocator 0044 implements an algorithm which jointly allocates a group of resources to a group of service requests, then the algorithm will process a group of requests from the Service Request Queue 3030 during any given time period.

An example of how an algorithm might jointly allocate a group of resources to a group of service demands follows (see Figure 16). Assume that:

- At time $T_1$, Allocator 0044 receives from $SDE_1$ a service request for transport of a low-priority transmission, e.g., a packet that is part of an email message.
- At time $T_2$ shortly after $T_1$, Allocator 0044 receives from $SDE_2$ a service request for transport of a high-priority transmission, e.g., a frame or packet that is part of a CBR transmission.
- At time $T_1$, Allocator 0044 receives from $SSE_1$ information about underutilized spectrum that is available long enough to support the size of the service request from $SDE_2$.
- At time $T_2$, Allocator 0044 receives from $SSE_2$ information about underutilized spectrum that is not available long enough to support the size of the service request from $SDE_2$.

A FCFS allocation algorithm would first allocate the low-priority packet to the underutilized spectrum available from $SSE_1$. However, the result is delay of the high-priority CBR transmission because the underutilized spectrum available from $SSE_2$ cannot support transmission of the high-priority CBR transmission.

An algorithm that jointly allocates a group of resources to a group of service demands during some time period could better reflect the differing priorities of individual service requests. In this example, such an algorithm would allocate the high-priority CBR transmission to the underutilized spectrum available from $SSE_1$, even though the Allocator 0044 receives the high-priority CBR transmission after it receives the low-priority email transmission.

For some number, including without limitation all, possible pair of resource and service demand subsets, the Channel Mapper 3016 creates and identifies possible one-to-one mappings of resource subset elements onto service demand elements.

The Network Performance Evaluator 3014 evaluates each mapping by some predefined performance criteria embodied in a network performance objective function. The Network Performance Evaluator 3014 evaluates network performance without considering bid and ask price specifications submitted by the SDE 0228 and SSE 0226. The Network Performance Evaluator 3014 objective function outputs may include without limitation: other sets, vectors, or scalars.

The Network Utility Evaluator 3008 associates bid and price specifications with each network relation considered, evaluates each relation by evaluating the value of the objective function computed by the Network Performance Evaluator 3014, and evaluates the bid and ask price specifications themselves. The Network Utility Evaluator 3008 employs some predefined objective function that depends on network performance, bid price specifications, and ask price specifications. The Network Utility Evaluator 3008 objective function outputs may include without limitation other sets, vectors, or scalars. The Network Utility Evaluator 3008 receives ask and bid price specifications from the Exchange 3004.

The Network Optimizer 3006 interprets the value of the objective function computed within the Network Utility Evaluator 3008 and Network Performance Evaluator 3014 for the mappings being considered. The Network Optimizer 3006 may compute an overall objective function based on the individual utility and performance objective functions described above.

The Network Optimizer 3006 also issues instructions to the Exchange 3004. These instructions may include without limitation: instructions to notify SDEs 0228 (buyers) and/or SSEs 0226 (sellers) of

pending channel assignments, instructions to solicit additional bids, requests to change the quantity of service requests or underutilized spectrum, or denials of service requests.

The Network Optimizer 3006 may exercise control over the Channel Mapper 3016 in order to impose a preference for certain channel mappings over others. The present invention may implement this feature for optimization methods including without limitation: first and higher order gradient searches and evolutionary algorithms such as genetic algorithms, neural network based algorithms, or simulated annealing methods.

The Exchange 3004 receives bid and ask price specifications from SDEs 0228 (buyers) and SSEs 0226 (sellers), respectively, and provides price specifications as required to the Network Utility Evaluator 3008. The Exchange 3004 implements negotiations between buyers and sellers and/or their respective agents (Section D.5. discusses the role of agents). The present invention considers a transaction cleared when some buyer is willing to assume ownership, temporary or otherwise, of some particular resource being offered and when some seller is willing to transfer ownership of such resource. In addition, the present invention considers a transaction cleared when the Exchange 3004 eliminates a bid or ask price specification for any other reason.

SDEs 0228 may withdraw or modify their service requests by notifying the Allocator 0044 via the SRE 0050. SSEs 0226 may withdraw or modify their resource offerings by notifying the SIE 0046. SDEs 0228 and SSEs 0226 modifying their respective requests and offerings must also simultaneously notify the Exchange 3004, since the bid and/or ask price specifications will no longer be meaningful.

The Exchange 3004 may impose conditions on the bid and ask price specifications, including without limitation: the time after which the specifications are considered to have expired if an associated transaction has not cleared.

When the Exchange 3004 determines that a transaction has cleared, it notifies the Channel Allocator 3002. The Channel Allocator 3002 updates the Resource Database 3010, updates the Service Request Queue 3030, notifies the Billing Application 3026, and notifies the SDE(s) and SSE(s) affected.

The Billing Application 3026 manages tracking, invoicing, and billing for resources transferred between parties. The Billing Application 3028 maintains a record of all activities within a Billing Database.

The Network Synchronizer 3022 synchronizes all time bases of the Allocator 0044, SDE(s) 0228, or SSE(s) 0226 as required in order to remove ambiguity from any interpretation of time resources or constraints.

In an alternate embodiment of Method D-1, both the Channel Mapper 3016 and Network Performance Evaluator 3014 may ignore some or all of the mappings before processing partitions within the Network Utility Evaluator 3008. In addition, the Network Utility Evaluator 3008 may ignore some or all of the mappings created within the Channel Mapper 3016. This feature would filter partitions and/or mappings that are obviously impractical (e.g., mapping a requirement for a 1.25 MHz IS-95 CDMA channel into an AMPS resource that has only 30 kHz available).

iv. Steps for Executing Method

Figure 16 contains a flow chart detailing the above procedure. Method D-1 executes Steps 3102, 3104, and 3106 concurrently. At Step 3102, the Service Request Queue 3030 loads service demands. At Step 3104, the Resource Database 3010 loads available resource data. At Step 3106, SDEs 0028 and SSEs 0026 transmit pricing specifications to the Exchange 3004.

At Step 3108, the Channel Mapper 3016 identifies possible mappings of resources into services.

At Step 3110, the Channel Mapper 3016 selects a mapping.

At Step 3112, the Network Performance Evaluator 3014 evaluates performance of the communications channels defined by the mapping as described above.

At Step 3114, the Network Utility Evaluator 3008 evaluates the utility of the communications channels defined by the mapping as described above.

At Step 3116, the Network Optimizer 3006 performs an overall evaluation of the Network that reflects the performance and utility evaluations executed by the Network Utility Evaluator 3008 and the Network Performance Evaluator 3014.

At Step 3118, the Network Optimizer 3006 determines whether some predetermined halting condition has been reached in the optimization process. The halting condition can include without limitation: a limit on the time of the search, a limit on the number of iterations, a condition in which the Network Optimizer 3006 evaluates all possible mappings, and when the Objective Function has reached a value that is within some predetermined tolerance.

If the halting condition has been reached at Step 3118, the Network Optimizer 3006 selects the particular set of resource and service partitions and the mapping relating the two partitions, which meet some predetermined condition on the objective functions calculated in the Network Performance Evaluator 3014 and/or Network Utility Evaluator 3008 and on the overall objective function calculated within the Network Optimizer 3006.

If the halting condition has not been reached at Step 3118, then Method D-1 returns to Step 3110 to select a new mapping.

If the halting condition has been reached, the Network Optimizer 3006 determines at Step 3122 whether SDEs 0228 and SSEs 0226 need to be notified before allocating channels to the SDE 0228. This case may occur, for example, when the ask price specifications contain a bidding provision that requires some delay before allocation to accommodate additional bids. If Step 3122 requires notification, the Channel Allocator 3002 notifies at Step 3124 the relevant SDEs 0228 and/or SSEs 0226 and the process returns to Step 3100. If not, then the Network Optimizer 3006 executes Step 3126.

At Step 3126, the Channel Allocator 3002 allocates the resources associated with the selected mapping to the service request associated with the selected mapping.

At Step 3128, the Channel Allocator 3002 updates the Resource Database 3010.

At Step 3130, the Channel Allocator updates the Service Demand Queue 3030.

At Step 3132, the Exchange 3004 notifies SDE 0228 and SSE 0226 of all allocations.

At Step 3134, the Exchange 3004 notifies the Billing Application 3026 to execute Step 3136 and Method D-1 returns to Step 3100.

At Step 3136, the Billing Application 3026 updates the Billing Database 3028.

A special case occurs when at Step 3120 the selected mapping is an empty set. This mapping implies that no mapping of resources to services was viable. In this case, the process executes as indicated, but many of the individual actions are trivial. At Step 3128, for example, the set of allocated resources is empty; at Step 3130, the action of updating the Resource Database 3010 is a null action; etc.

b. Example Application No. 1: AMPS and CDMA Operator Contending for Underutilized Spectrum

At time 0900 on any given day, a SSE 0226 offers 30 kHz of spectrum for 1 hr within a particular coverage area. It does not restrict use of specific modulations and polarizations. It offers the spectrum at $3.00 ($0.05/min).

A particular CDMA operator requires 1.25 MHz of spectrum for intermittent downstream data transmissions from time 0900 to time 1000. The CDMA operator's coverage area coincides with that associated with the resource offered. The CDMA operator bids $1.80 for the service ($0.03/min).

A particular AMPS operator requires 30 kHz for intermittent voice calls during the same time interval and also lies within the same coverage area. The operator bids $1.20 ($0.02/min).

In this particular embodiment of the SAE 0048, the present invention defines a network performance objective function, $\Psi_p$, as the number of services that a given mapping can fulfill within a given mapping.

The present example assigns the network utility objective function, $\Psi_u$, a value of one if the bid and ask prices are equal and zero otherwise. The present example assigns the utility objective function a value of zero if the mapping evaluated is an empty set.

The present example computes the overall objective function as the product of $\Psi_p$ and $\Psi_u$.

The Network Optimizer 3006 will select the mapping resulting in the highest value of $\Psi$ unless that value is zero. If $\Psi = 0$ for all mappings, then the Network Optimizer 3006 will classify as "best" the partitions and mapping which result in the highest value of $\Psi_p$ unless that value is also zero. If $\Psi_p = 0$ for all mappings, the Network Optimizer 3006 will return the empty set.

The halting condition for the Network Optimizer 3006 occurs when it has evaluated all possible mappings. (In this example, the halting condition occurs with exhaustive search. However, as discussed earlier, Method D-1 includes halting conditions other than exhaustive search.)

In this example, the Optimizer will not consider alternative mappings from resources that have not been made available.

The table below summarizes these conditions:

| | |
|---|---|
| R1 | {30 kHz of spectrum within coverage area for 1 hr, any polarization, any modulation} |
| S1 | {CDMA downlink for 1 hr} |
| S2 | {AMPS downlink for 1 hr} |
| A1 | {$3.00} |
| B1 | {$1.80} |
| B2 | {$1.20} |
| $\Psi_p$ | Defined as the number of services supported |
| $\Psi_u$ | 1 if **A'**=**B'**, 0 otherwise |
| $\Psi$ | $\Psi_p \times \Psi_u$ |

The SIE 0046 processes the resource data and the SRE 0050 processes the service request data above. Following the process above, the actions listed in the table below occur:

| Step | Action |
|---|---|
| 3102 | The CDMA operator's demand is identified as S1 and loaded into the Service Request Queue; The AMP's operator's demand is identified as S2 and loaded into the Service Request Queue; The Service Partitioner loads both demands. |
| 3104 | The 30 kHz resource is identified as R1 and loaded into the Resource Database. |
| 3106 | The Exchange receives the price specifications defined above. |
| 3108 | The Channel Mapper defines all possible mappings of the available resources, following the algorithm described above. The possible mappings are: $P(M) = \{\phi, \{(R1,S1)\}, \{(R1,S2)\}\}$ where $\phi$ |

| | |
|---|---|
| | is the empty set. Define P(M) = {M1, M2, M3}. |
| 3110 | The Channel Mapper selects mapping M1. |
| 3112 | The Network Performance Evaluator evaluates the performance of M1 (the empty set). Since no services are enabled, $\Psi_p = 0$. |
| 3114 | The Network Utility Evaluator evaluates the utility of M1. Since M1 is empty, $\Psi_u = 0$. |
| 3116 | The Network Optimizer evaluates the overall objective function for M1. The result is $\Psi = 0$. |
| 3118 | The halting condition has not been met, so Method D-1 executes Step 3110. |
| 3110 | The Channel Mapper selects mapping M2. |
| 3112<br><br>3114 | The Network Performance Evaluator evaluates the performance of M2 ({(R1,S1)}). Since a CDMA downlink requires 1.25 MHz and R1 provides only 30 kHz, $\Psi_p = 0$.<br>The Network Utility Evaluator evaluates the utility of M2. Since A1>B1, $\Psi_u = 0$. |
| 3116 | The Network Optimizer evaluates the overall objective function for M2. The result is $\Psi = 0$. |
| ... | |
| 3112<br><br>3114 | The Network Performance Evaluator evaluates the performance of M3 ({(R2,S1)}). Since an AMPS downlink requires only 30 kHz and R1 provides 30 kHz, $\Psi_p = 1$.<br>The Network Utility Evaluator evaluates the utility of M3. Since A1>B2, $\Psi_u = 0$. |
| 3116 | The Network Optimizer evaluates the overall objective function for M3. The result is $\Psi = 0$. |
| 3118 | Since the halting condition - all mappings evaluated - has been reached, Method D-1 executes Step 3120. |
| 3120 | The Network Optimizer selects mapping M3 = {(R1,S2)} |
| 3122 | No notification is required under the pricing specifications. |
| 3128 | The selected mapping is an empty set, so no resources are allocated. |
| 3130 | No change is made to the Resource Database. |
| 3132 | No change is made to the Service Demand Queue. |
| 3134 | Suppliers and demanders are notified of the outcome of the allocation process. |
| 3136 | The billing application is notified, but no action is required on its part. |

At this point, both SDEs 0228 realize that the SAE 0048 will not fulfill their requirements. Because the SDEs 0228 and SSE 0226 can observe the outcome of the actions of the SAE 0048, they may choose to modify resource offerings, service requests, and/or bid and ask prices. In this case, assume that: (a) the SSE 0226 lowers the ask price from \$0.05/min to \$0.04/min; (b) the CDMA operator requests 30 kHz instead of 1.25 MHz, intending to use alternative equipment capable of operating in 30 kHz; (c) the CDMA operator simultaneously increases the bid to \$0.04/min; and (d) the AMPS operator increases its bid to \$0.03/min.

During the next iteration of the process, the following events occur:

| Step | Action |
|---|---|
| ...<br>3112 | The Network Performance Evaluator evaluates the performance of M2 ({(R1,S1)}). Since the CDMA operator is now only requesting a 30 kHz downlink, $\Psi_p = 1$. |
| 3114 | The Network Utility Evaluator evaluates the utility of M2. Since now A1=B1, $\Psi_u = 1$. |
| 3116 | The Network Optimizer evaluates the overall objective function for M2. The result is $\Psi = 1$. |
| ...<br>3112 | The Network Performance Evaluator evaluates the performance of M3 ({(R2,S1)}). As before, $\Psi_p = 1$. |
| 3114 | The Network Utility Evaluator evaluates the utility of M3. Since A1>B2, $\Psi_u = 0$. |
| 3116 | The Network Optimizer evaluates the overall objective function for M3. The result is $\Psi = 0$. |
| 3118 | Since the halting condition - all mappings evaluated - has been reached, the process executes Step 3120. |
| 3120<br>3122 | Under the guidelines above, the {(R1,S1)} is selected.<br>No notification is required under the price specifications. |
| 3126 | R1 (30 kHz) is allocated to S1 (the CDMA operator's 30 kHz service). |

| | |
|---|---|
| 3128 | The Resource Database is updated (R1 is removed). |
| 3130 | The Service Demand Queue is updated (S2 is returned). |
| 3132 | Suppliers and demanders are notified of the allocation. |
| 3134 | The Billing Application is notified. |
| 3136 | The Billing Application updates the Billing Database. |

c. Example Application No. 2: Real-Time Spectrum Auction

The present invention defines sets **A(t)** and **B(t)** in general as asking and bid price *specifications*, although in the previous example they were embodied as actual prices. In an auction scenario, the present example can structure $A_i(t)$ such that it takes the value of the highest corresponding bid price for three consecutive iterations. If the highest bid is increased during that time, then the first wait interval is cancelled and a new one begins. If no higher bid is received, then after three intervals $A_i(t)$ automatically converts to a standard ask price and the transaction may be cleared.

The rest of the example will follow Example 1, but with the following initial conditions:

| | |
|---|---|
| R1 | {30 kHz of spectrum within coverage area for 1 hr, any polarization, any modulation} |
| S1 | {AMPS downlink for 1 hr} |
| S2 | {AMPS downlink for 1 hr} |
| A1 | {$1.67 minimum initial bid; auction procedure as defined above} |
| B1 | {$1.80} |
| B2 | {$1.20} |
| $\Psi_p$<br>$\Psi_u$ | Defined as the number of services supported.<br>1 if **A'=B'**, 0 otherwise; Also assigned value of 1 if auction rules followed. |
| $\Psi$ | $\Psi_p \times \Psi_p$ |

The results of the SAE process are as follow:

| Step | Action |
|---|---|
| ... | |
| 3108 | P(**M**) – {$\phi$, {(R1,S1)}, {(R1,S2)}} |
| ... | |
| 3112 | $\Psi_p$(M2) – 1, since the AMPS service requested can be served by R1 (30 kHz of spectrum). |
| 3114 | $\Psi_u$(M2) = 1, since the minimum initial bid requirement was met. |
| 3116 | $\Psi$(M2) = $\Psi_p \times \Psi_u$ = 1. |
| ... | |
| 3112<br>3114 | $\Psi_p$(M3) = 1, since the AMPS service requested can be served by R1 (30 kHz of spectrum).<br>$\Psi_u$(M3) – 0, since the minimum initial bid requirement was not met. |
| 3116 | $\Psi$(M3) = $\Psi_p \times \Psi_u$ = 0. |
| ... | |
| 3120 | M2 is selected as best mapping for market. |
| 3122 | Notification is required under pricing specifications (auction). |
| 3124 | SAE notifies market that M2 is the impending choice. |
| ... | |

Following the above notification, the second operator elects to bid $1.83, which beats B1. If the first operator elects not to outbid the second, the following actions take place:

| Step | Action |
|---|---|
| ... | |
| 3108<br>... | P(**M**) = {$\phi$, {(R1,S1)}, {(R1,S2)}} |

| | |
|---|---|
| 3112<br>3114 | $\Psi_p(M2) = 1$, since the AMPS service requested can be served by R1 (30 kHz of spectrum).<br>$\Psi_u(M2) = 0$, since the user has been outbid. |
| 3116 | $\Psi(M2) = \Psi_p \times \Psi_u = 1$. |
| ... | |
| 3112 | $\Psi_p(M2) = 1$, since the AMPS service requested can be served by R1 (30 kHz of spectrum). |
| 3114<br>3116 | $\Psi_u(M3) = 1$, since the service requester has the highest bid.<br>$\Psi(M3) = \Psi_p \times \Psi_u = 0$. |
| ...<br>3120 | M2 is selected as best mapping for market. |
| 3122<br>3124<br>... | Notification is required under pricing specifications (auction).<br>Market is notified that M3 is the impending choice. |
| 3126<br>... | SAE allocates R1 to S2. |

d. Example Application No. 3: Maximizing and Balancing Throughput Under Service Level Agreement

In this example, R(t) consists of 1000 1-kHz parcels of spectrum in the 700 MHz band that will be available within a particular coverage area for some specified time. The SSE 0226 imposes a restriction on the coverage area - the space resource – that limits the output power of any transmitting station to 1 watt. The SSE 0226 imposes no restrictions on polarization or code resources.

Two sharing operators require a downlink channel for data transmission. A Service Level Agreement (SLA) between the two operators and the owner of the shared spectrum requires that spectrum be allocated to the two users such that capacity is maximized and such that no user is permitted greater throughput than the other.

Both of the operators' base stations are colocated within the coverage area, but the mobile station in the first operator's network is 1 km away from the base station, while the second mobile station is 2 km away. The present example assumes all stations to employ isotropic antennas (equal coverage in all directions).

For simplicity, the present example assumes both mobile stations to have identical receivers and both downlinks to be in free space with spectral efficiencies of 0.5 times the theoretical (Shannon) limit. The receiver noise temperatures are 1000 K. The present example also assumes that both base and mobile stations employ software defined radios (SDRs) that can function over arbitrary channel bandwidths from 700-701 MHz.

Method D-1 defines the resource and service request domains:

$$\mathbf{R(t)} = \{ \text{R1, R2, R3, R4, R5, \ldots, R1000} \}$$

$$\mathbf{S(t)} = \{ \text{S1, S2} \}$$

Method D-1 defines the channel performance objective function, $\Psi_p$, in terms of the theoretical Shannon capacity limits in free space for the links that will use the channel:

$$C = B \log_2(1 + S/N)$$

where $C$ is the theoretical capacity in bits per second, $B$ is the channel bandwidth in Hz, and $S/N$ is the channel signal-to-noise ratio. The channel signal power can be determined from the Friis equation for free space transmission:

$$S = (P_T/(4\pi R^2))(\lambda^2/4\pi)$$

where $P_T$ is the transmitter output power in watts, $R$ is the line-of-sight distance from the transmitter to the receiver, $\lambda$ is the wavelength in free space ($c_0/f$, where $f$ is the carrier center frequency in Hz and $c_0$ is the propagation velocity of light in free space).

The receiver noise power, $N$, can be approximated from the Rayleigh-Jeans formula:

$$N = kTB$$

where $k$ is Boltzman's constant, $T$ is the receiver noise temperature in Kelvin, and $B$, again, is the channel bandwidth. Thus, the complete expression for the theoretical link capacity is:

$$C = B \log_2 ( 1 + (c_0/4\pi Rf)^2 (P_T/(kTB)) )$$

Given that $R_1 = 2R_2$, where $R_1$ is the distance from the base station location to the first operator's mobile station and $R_1 - 2R_2$ is the distance from the base station location to the second mobile station; and that each operator will be sharing some maximum amount of spectrum, $B_0$, the individual capacities can be written:

$$C_1 = \alpha B_0 \log_2 ( 1 + \gamma_0/\alpha )$$

$$C_2 = (1\text{-}\alpha)B_0 \log_2 ( 1 + \gamma_0/(1\text{-}\alpha) )$$

where

$$\gamma_0 = (c_0/4\pi R_0 f)^2 (P_T/(kTB_0))$$

and $R_0 = R_1$.

In order to balance throughputs, Method D-1 defines the channel mapping objective function to the ratio of $C_1$ to $C_2$:

$$\Psi_p = C_1/C_2$$

Method D-1 defines the utility objective function, $\Psi_p$, as unity; sets the overall objective function, $\Psi$, equal to $\Psi_p$. The overall goal of the Network Optimizer will be to force $\Psi$ to a value of $\Psi = 1$. Method D-1 will halt the process when this condition occurs.

Following the format of the previous example,

| | |
|---|---|
| R1 | {700.000-700.001 MHz within coverage area for 1 hr, any polarization, any modulation} |
| R2 | {700.001-700.002 MHz within coverage area for 1 hr, any polarization, any modulation} |
| ... | |
| R1000 | {700.999-701.000 MHz within coverage area for 1 hr, any polarization, any modulation} |
| S1 | {Maximum possible throughput} |
| S2 | {Maximum possible throughput} |
| A1 | {Service level agreement (SLA) to provide shared capacity to Operator #1 and #2} |
| ... | |
| A1000 | {Service level agreement (SLA) to provide shared capacity to Operator #1 and #2} |
| B1 | {SLA to share available capacity with Operator #2} |
| B2 | {SLA to share available capacity with Operator #1} |
| $\Psi_p$ | Ratio of throughput estimates using Shannon capacity formula and Friis transmission equation |
| $\Psi_u$ | 1 |
| $\Psi$ | $\Psi_p$ |

The results of the SAE process are as follow:

| Step | Action |
|---|---|
| ... | |
| 3108 | $P(M) = \{\phi, \{(R2,S2), (R2, S2), \ldots, (R1000, S2)\},$<br>$\{(R1,S1), (R2, S2), \ldots, (R1000, S2)\}$<br>$\{(R1,S1), (R2,S1), (R3,S2), \ldots, (R1000,S2)\},$<br>$\{(R1,S1), (R2,S1), (R3,S1), (R4,S2), \ldots, (R1000,S2)\},$<br>$\ldots,$<br>$\{(R1,S1), (R2,S1), (R3,S1), \ldots, (R1000,S1)\}, \ldots \}$ |
| ... | |
| 3112 | Figure 18 plots the theoretical capacity (Shannon limit) of both services as a function of the % of total available spectrum allocated to the first operator. With M2 = {(R1,S2), (R2, S2), ..., (R1000, S2)} (i.e. S2 gets all the spectrum while S1 gets none), the capacity available to S1 is 0 Mbps and the capacity available to S2 is approximately 14 Mbps under the stated conditions. The ratio is 0, so that $\Psi_p(M2) = 0$. |
| 3118 | Since not all mappings have yet been considered, the process executes Step 3116. |
| ... | |
| 3112 | With M3 = {(R1,S1), (R2, S2), ..., (R1000, S2)}, the capacity available to S1 is now approximately 26 kbps, while that available to S2 remains at approximately 14 Mbps. The ratio $\Psi_p(M3)$ is approximately 0.002. |
| ... | |
| 3112 | Under the scenario described above, with M466 = {(R1,S1),...(R466,S1), (R467,S2),..., (R1000,S2)}, the capacity of both links is approximately 8.1 Mbps. The ratio $\Psi_p(M466)$ is approximately 1. |
| 3118 | At this point, Method D-1 reaches the halting condition. |
| ... | The remainder of the process will allocate R1 through R466 to S1; and R467 through R1000 to S2. |

Note that M466 is not the only mapping that would satisfy the halting condition; only the one that produced contiguous blocks of spectrum. Any mapping that would allocate about 47% of the available spectrum to S1 and 53% to S2 would have satisfied the objective. Since the present invention assumes that receivers and transmitters are SDRs, they could have implemented, for example, a frequency hopping sequence using the same amount of noncontiguous spectrum.

e. Example Application No. 4: Enabling Transmission of CBR Traffic Across Different Spectrum Bands

In this example, Method D-1 reserves channel resources to enable the transmission of delay-sensitive CBR traffic for some extended time period. A Competitive Local Exchange Carrier (CLEC) implements a Wireless Local Loop (WLL) CBR service using, in part, underutilized spectrum made available through use of the Allocator 0044 and multiple SSEs 0226. The CLEC Sharing Operator determines that it needs 30 kHz of spectrum during the peak hour each day (time 1100-1200) in order to provide service to a particular area. The Sharing Operator is willing to pay a total of no more than $1.80 to enable this additional service. Otherwise, the Sharing Operator will decide not to enable the service and will simply block calls if the system is at capacity. The Sharing Operator's subscriber equipment can operate in the 869-896 MHz and 1930-1990 MHz bands.

Four wireless operators make the following spectrum available:

Operator A: 30 kHz in the 869-896 MHz band from time 1100-1120 at $0.03/min
Operator B: 30 kHz in the 1930-1990 MHz band from time 1115-1140 at $0.025/min
Operator C: 30 kHz in the 869-896 MHz band from time 1140-1200 at $0.025/min
Operator D: 30 kHz in a 700 MHz band from time 1100-1200 at $0.03/min

The SSEs 0226 impose no restrictions on modulation or polarization. The SSEs 0226 restrict power to the normal operating power limits of the Sharing Operator.

In this example, Method D-1 uses the following objective functions: (1) the network performance objective function, $\Psi_p$, as the number of services that a given mapping can fulfill; (2) the network utility function, $\Psi_u$, as 1 if the bid price specification is met, and 0 otherwise; and (3) the overall objective function, $\Psi$, as the product of the two underlying objective functions.

Method D-1 defines the halting condition so that the process will halt as soon as viable allocation ($\Psi = 1$) is found or until it considers all alternatives. No notification is required before, as defined in Step 3122.

The scenario conditions are summarized as follows:

| | |
|---|---|
| R1 | {30 kHz in the 869-896 MHz band from time 1100-1120} |
| R2 | {30 kHz in the 1930-1990 MHz band from time 1115-1140} |
| R3 | {30 kHz in the 869-896 MHz band from time 1140-1200} |
| R4 | {30 kHz in the 700 MHz band from time 1100-1200} |
| S1<br>A1 | {WLL CBR service requiring 30 kHz between time 1100-1200 and conforming to all SSE space, power, polarization, and modulation restrictions with station capabilities limited to operation in the 869-896 MHz or 1930-1990 MHz bands}<br>{\$0.03/min (\$0.60 total)} |
| A2<br>A3<br>A4<br>B1 | {\$0.025/min (\$0.625 total)}<br>{\$0.025/min (\$0.50 total)}<br>{\$0.03/min (\$1.80 total)}<br>{\$1.80 total} |
| $\Psi_p$ | Defined as the number of services supported. |
| $\Psi_u$ | 1 if total cost to Sharing Operator is less than or equal to B1; 0 otherwise. |
| $\Psi$ | $\Psi_p \times \Psi_p$ |

The process executes Steps 3100 through 3108 as before. At Step 3108, the SAF Resource-to-Demand Mapper 0214 identifies the following possible mappings:

| Mapping | Pairs |
|---|---|
| M1 | $\phi$ |
| M2 | (R1,S1) |
| M3 | (R2,S1) |
| M4 | (R3,S1) |
| M5 | (R4,S1) |
| M6 | (R1,S1), (R2,S1) |
| M7 | (R1,S1), (R3,S1) |
| M8 | (R1,S1), (R4,S1) |
| M9 | (R2,S1), (R3,S1) |
| M10 | (R3,S1), (R4,S1) |
| M11 | (R1,S1), (R2,S1), (R3,S1) |
| M12 | (R1,S1), (R3,S1), (R4,S1) |
| M13 | (R2,S1), (R3,S1), (R4,S1) |
| M14 | (R1,S1), (R2,S1), (R4,S1) |
| M15 | (R1,S1), (R2,S1), (R3,S1), (R4,S1) |

The process proceeds as follows:

| Step | Action |
|---|---|
| ...<br>3108<br>... | P(M) = {M1, M2, ..., M15} |
| 3110<br>3112 | M2 = {(R1,S1)} is selected.<br>Since R1 only provides 20 min and 60 min is required, $\Psi_p = 0$. |

| | |
|---|---|
| 3114<br>3116 | Since A1 = \$0.60 < B1 = \$1.80, $\Psi_u = 1$.<br>$\Psi = \Psi_p \times \Psi_u = 0 \times 1 = 0$. |
| 3118 | The halting condition - $\Psi = 1$ or all mappings evaluated - has not been reached, so the process returns to Step 3110. |
| 3110 | M3 = {(R2,S1)} is selected. |
| 3112 | Since R2 only provides 25 min and 60 min is required, $\Psi_p = 0$. |
| 3114 | Since A2 = \$0.625 < B1 = \$1.80, $\Psi_u = 1$. |
| 3116 | $\Psi = \Psi_p \times \Psi_u = 0 \times 1 = 0$. |
| ... | |
| 3110 | M6 = {(R1,S1), (R2,S1)} is selected. |
| 3112 | Since R1 and R2 together provide only 45 min and 60 min is required, $\Psi_p = 0$. |
| 3114 | Since (A1 + A2) = \$1.225 < B1 = \$1.80, $\Psi_u = 1$. |
| 3116<br>... | $\Psi = \Psi_p \times \Psi_u = 0 \times 1 = 0$. |
| 3110<br>3112 | M11 = {(R1,S1), (R2,S1), (R3,S1)} is selected.<br>R1, R2, and R3 together provide continuous availability from 1100 to 1200. Since all other service requirements are also met, $\Psi_p = 1$. |
| 3114 | Since (A1+A2+A3) = \$1.725 < B1 = \$1.80, $\Psi_u = 1$. |
| 3116 | $\Psi = \Psi_p \times \Psi_u = 1 \times 1 = 1$. |
| 3118<br>3120 | In this case, the halting condition has been met.<br>Mapping M11 selected. |
| 3122<br>3126<br>... | No notification required.<br>SAE allocates resources R1, R2, and R3 to service demand S1. |

Because of the actions of the SAE 0048, allocations within 2 different bands at three different time intervals will fulfill a single service request, S1.

## D.5. Method for Employing Software Agents in Automating Spectrum Markets

The present invention includes a method that uses intelligent software agents for automating the process of buying and selling underutilized spectrum. In the present invention, an intelligent software agent is an autonomous, collaborative, persistent, mobile, and adaptive software component that can infer and execute required actions, and seek and incorporate relevant information given certain goals. These self-ruling software entities use rules, knowledge, facts, and problem-solving strategies related to user preferences to learn, reason, and make decisions on behalf of users. Furthermore, since the intelligent agents are mobile after being dispatched by an exchange, they can move throughout networks as needed to execute processes and automatically send information to users. The persistence characteristic enables the agent to continue to execute long after the machine that launched it is removed from the network.

Agent technology has yielded benefits in a number of application categories, including without limitation:

- User mobility where there is: (1) intermittent connectivity, (2) low bandwidth, and (3) limited local storage;
- Information retrieval in heterogeneous networks with local real-time interaction requirements;
- Robust transaction with remote servers; and
- Large scale asynchronous transactions such as internet commerce.

Other applications of the agent technology include personal assistance, secure brokering, telecommunication networks services, and monitoring and notification.

In the preferred embodiment of the present invention, intelligent software agents will operate on behalf of SDEs 0228 and SSEs 0226 in the buying and selling, respectively, of underutilized spectrum. Unlike methods of bandwidth auction implemented in other markets, the Exchange does not notify SDEs directly when SSEs make

underutilized spectrum available for auction. Furthermore, software agents, operating on behalf of SDEs and SSEs, can adjust their negotiation strategies based on feedback received. The agents can use rules, knowledge, facts, and patterns gathered from historical auction or exchange data, SSEs, and SDEs to gain new knowledge to use when negotiating for available spectrum.

**METHOD D-2**: *Method of Employing Software Agents in Automating Spectrum Markets.*

Method D-2 uses intelligent software agents for automating the process of buying and selling underutilized spectrum.

a. Relationship to Overall Method A-2

In one embodiment of the present invention, Method D-2 implements the functions of Exchange 3044 within the Allocator 0044 by utilizing intelligent software agents. The intelligent software agents use data provided by SDEs 0228 and SSEs 0226 to automate the buying and selling of available spectrum.

b. Structure of Block Diagram

Figure 19 shows the entities required to implement an agent-based exchange of available spectrum.

i. Bidding Price (BP) agents 3302 operate on behalf of SDEs 0228.

ii. Asking Price (AP) agents 3304 operate on behalf of SSEs 0226.

iii. The BP Agent Database (BPDB) 3306 stores the information Method D-2 needs to buy underutilized spectrum efficiently, including without limitation: profiles, rules, facts, patterns, and historical data from sources of such information, including without limitation: auctions, exchanges, or SDEs 0228.

iv. The AP Agent Database (APDB) 3308 stores the information Method D-2 needs to sell underutilized spectrum efficiently, including without limitation: rules, facts, patterns, and historical data from sources of such information, including without limitation: auctions, exchanges, or SSEs 0226.

v. The Exchange 3004 processes ask and bid specifications from the SSEs 0226 (i.e., sellers) and SDEs 0228 (i.e., buyers), respectively.

vi. The Exchange 3004 manages the creation of and negotiations between BP agents 3302 and AP agents 3304, in addition to implementing the functions specified in Method D-1.

c. Functional Relationships in Block Diagram

The AP agent 3304 operates on behalf of the SSE 0226 and provides information to the Exchange 3004 on asking pricing specifications for available resources. Once the SSE 0226 has registered with the Exchange 3004, both parties create an AP agent 3304 as the representative of the SSE 0226. The AP agent 3304 provides ask price specifications to the Exchange 3004. The Exchange 3004 communicates any instructions received from the Network Optimizer 3006 to the AP agent 3304. If the ask price specifications are not met, the AP agent 3304 can based on learning and reasoning use the information received from the Exchange 3004 and the APDB 3308 to determine whether to adjust asking price specifications and resubmit the ask price specifications. Upon completing any transactions between the agents, the Exchange 3004 stores detailed data at the APDB 3308 about the exchange or auction.

The APDB 3308 stores the information Method D-2 needs to sell underutilized spectrum efficiently, including without limitation: profiles, rules, facts, patterns, or other data sources of such information, including without limitation: auctions, exchanges, or SSEs 0226. When a SSE 0226 registers with the Exchange 3004, the Exchange 3004 creates a profile of the SSE 0226 and stores the profile in the APDB 3308. The profile may include without limitation: contact information, registration information, user preferences, asking price facts and rules, and/or special instructions. In addition to using information

received from the Network Optimizer 3006 via the Exchange, the AP agent 3304 may also use information retrieved from the APDB 3308 to gain knowledge and create new negotiation strategies and/or profiles. Upon completing any transactions between the agents, the Exchange 3004 stores detailed data in the APDB 3308 about the exchange or auction.

The BP agent 3302 operates on behalf of the SDE 0228 and provides information to the Exchange 3004 on bidding price specifications and services requested by SDEs 0228. Once the SDE 0228 registers with the Exchange, both parties create a BP agent 3302 as the representative of the SDE 0228. The BP agent 3302 provides bid price specifications to the Exchange. The Exchange 3004 communicates any instructions received from the Network Optimizer 3006 to the BP agent 3302. If the bid price specifications are not met, the BP agent 3302 can based on learning and reasoning use the information received from the Exchange 3004 and the BPDB 3306 to determine whether to adjust bidding price specifications and resubmit the bid price specifications. Upon completing any transactions between the agents, the Exchange 3004 stores detailed data at the BPDB 3306 about the exchange or auction.

The BPDB 3306 stores the information Method D-2 needs to sell underutilized spectrum efficiently, including without limitation: profiles, rules, facts, patterns or other data sources of such information, including without limitation: auctions, exchanges, or SDEs 0228. When a SDE 0228 registers with the Exchange 3004, the Exchange 3004 creates a profile of the SDE 0228 and stores the profile in the BPDB 3306. The profile may include without limitation: contact information, registration information, user preferences, bidding price facts and rules, and/or special instructions. In addition to using information received from the Network Optimizer 3006 via the Exchange, the BP agent 3302 may also use information retrieved from the BPDB 3306 to gain knowledge and create new negotiation strategies and/or profiles. Upon completing any transactions between the agents, the Exchange 3004 stores detailed data in the BPDB 3306 about the exchange or auction.

The Exchange 3004 handles all communication between the BP agents 3302, AP agents 3304, Network Optimizer 3006, and Network Utility Operator 3008. The Exchange 3004 is responsible for registering SSEs 0226 and SDEs 0228 and creating their AP and BP agent representatives, 3304 and 3302, respectively, that operate on their behalf. The Exchange 3004 routes bidding and asking price specifications received from the BP and AP agents to the Network Utility Evaluator 3008. The Exchange 3004 communicates instructions received from the Network Optimizer 3006 to the AP and BP agents. The Exchange 3004 manages multiple AP and BP agents participating in the bidding and selling process. The Exchange 3004 closes or clears bidding sessions. The Exchange 3004 stores, retrieves, and updates data to the APDB 3308 and BPDB 3306.

d. Steps for Executing Method

Figure 19 contains a flow chart detailing the above procedure.

At Steps 3202 and 3212, the Agent-Based market exchange begins with checking for incoming ask or bid price specifications.

If ask price specifications exist, Step 3204 verifies that the supplier registered with the Exchange. If the supplier has not registered, Method D-2 executes Steps 3206-3210.

At Step 3206, the Exchange 3004 creates a profile of the supplier.

At Step 3208, the Exchange 3004 stores the supplier registration information and pricing specifications in the APDB 3308.

At Step 3210, Method D-2 creates an AP agent 3304 to function as the supplier's representative. Consequently, if the supplier already registered with the Exchange 3004, Method D-2 executes only Steps 3208 and 3210.

If bid price specifications exist, Step 3214 verifies that the demander registered with the Exchange. If the demander has not registered, Method D-2 executes Steps 3216-3220.

At Step 3216, Exchange 3004 creates a profile of the demander is created.

At Step 3218, the Exchange 3004 stores the service demander registration information and pricing specifications in the BPDB 3306.

At Step 3220, Method D-2 creates a BP agent to function as the demander's representative. Consequently, if the demander already registered with the Exchange 3004, Method D-2 executes only Steps 3218 and 3220.

At Step 3222, any pending pricing specifications are passed to the Exchange.

At Step 3224, the Exchange 3004 passes the pricing data to the Network Utility Evaluator to identify and select the best mappings for the market.

At Step 3226, the Exchange 3004 processes instructions resulting from the Network Optimizer in Step 3224.

If, at Step 3228, the Exchange 3004 determines that the transaction should be terminated, the Exchange clears the transaction in Step 3246, and notifies the SDEs 0228 and SSEs 0226 in Step 3248.

At Steps 3230 and 3238, if the ask and bid price specifications are met, the Exchange clears the transaction in Step 3246, updates the APDB 3308 and BPDB 3306 in Step 3252, and notifies the Channel Allocator in Step 3250 to allocate available resources to service demands as appropriate.

If the bid specification is met in Step 3230 and the ask specification is not met in Step 3238, the Exchange 3004 notifies AP agent 3304 in Step 3240.

At Step 3242, the AP agent 3304 operates as the SSE's representative and requests rules, facts, patterns, historical data, and other information from the APDB 3308.

If at Step 3244 the AP agent 3304 can infer new ask price specifications based on knowledge gained in Step 3242, the Exchange 3004 executes Steps 3222 through 3228 until it clears the transaction. If the AP agent 3304 cannot infer new ask price specifications, the Exchange 3004 clears the transaction in Step 3246, updates the APDB 3308 and BPDB 3306 in Step 3252, and notifies the SDEs and SSEs in Step 3248.

If the bid specification is not met in Step 3230, Exchange 3004 notifies the BP agent in Step 3232.

At Step 3234, the BP agent 3302 operates as the SDE's representative and requests rules, facts, historical data, and other information from the BPDB 3306.

If at Step 3236 the BP agent can infer new bid price specifications based on knowledge gained in Step 3234, the Exchange 3004 executes Steps 3222 through 3228 until it clears the transaction. If the BP agent 3302 cannot infer new bid price specifications, the Exchange 3004 clears the transaction in Step 3246, updates the APDB 3308 and the BPDB 3306 in Step 3252, and notifies the SDEs and SSEs in Step 3248.

e. Example: Agent Negotiation for Underutilized Spectrum

At 0900 on a particular day, a supplier offers 30 kHz of spectrum for 1 hr within a particular coverage area. The supplier does not restrict use of specific modulations and polarizations. The supplier offers the spectrum at $2.50/min.

A particular CDMA operator requires 1.25 MHz of spectrum for intermittent downstream data transmissions from 0900 to 1000. The CDMA operator's coverage area coincides with that associated with the resource offered. The CDMA operator bids $1.80/min for the service.

A particular AMPS operator requires 30 kHz for intermittent voice calls during the same interval and also lies within the same coverage area. The operator bids $1.40/min.

The following table summarizes these conditions:

| | |
|---|---|
| R1 | {30 kHz of spectrum within coverage area for 1 hr, any polarization, any modulation} |
| S1 | {CDMA downlink for 1 hr} |
| S2 | {AMPS downlink for 1 hr} |
| A1 | $2.50/min |
| B1 | $1.80/min |
| B2 | $1.40/min |

Negotiation Rules to be used by Agents:

| | |
|---|---|
| R1-Rule1 | Adjust original ask price only after bid price is rejected once and services can be filled. |
| R1-Rule2 | If bid price is within 20% of original ask price, accept bid price. |
| R1-Rule3 | If more than one bid price within 20% of original ask price, accept highest bid price. |
| S1 | No rules. |
| S2-Rule1 | If bid price is rejected and services can be filled, adjust current bid price by 15% and resubmit bid. |
| S2-Rule2 | A bid may be resubmitted a maximum of 3 times. |
| S2-Rule3 | Maximum bid price cannot exceed $2.00/min. |

Method D-2 executes the following process:

| Step | Action |
|---|---|
| 3102 | The CDMA operator's demand is identified as S1 and loaded into the Service Request Queue;<br>The AMP's operator's demand is identified as S2 and loaded into the Service Request Queue;<br>Both demands are loaded by the Service Partitioner |
| 3108 | The 30 kHz resource is identified as R1 and loaded into the Resource Database. |
| ... | |
| 3202<br>3208 | The Exchange retrieves the pending price specifications from the SSE for R1.<br>The Exchange updates the APDB with negotiation strategies to be used by the AP agent. |
| 3210<br>3212<br>3218<br>3220 | The Exchange creates AP1 agent to operate on behalf of R1 using price identified by A1.<br>The Exchange retrieves pending price specifications from the SDE for S1 and S2.<br>The Exchange updates the BPDB with negotiation strategies to be used by the BP agents.<br>The Exchange creates a BP1 and BP2 agent to operate on behalf of S1 and S2, respectively. |
| 3222 | The Exchange retrieves the price specifications from the AP1, BP1, and BP2. |
| 3224 | The Exchange passes the price specifications to the Network Utility Evaluator. The Network Utility Evaluator evaluates the necessary mappings created by the Channel Mapper. The Network Performance Evaluator determines the best mapping for the required specifications. |
| 3226 | The Network Performance Evaluator reports:<br>BP1 request for services cannot be mapped to required resources.<br>BP2 request for services can be mapped to required resources but bid price is not acceptable. |
| 3230 | Bid specifications for S1 are not met, so the Exchange notifies BP1 in Step 3232. Since there are no negotiating rules provided by S1 in Step 3234, a new bid cannot be calculated therefore, Steps 3236, 3246, and 3248 are executed. The BP1 agent is deactivated and S1 is notified of results.<br><br>Bid Specifications are met for S2, so Step 3238 is executed. In Step 3238 the ask price specification is not met, so the Exchange notifies AP1 and BP2 in Steps 3240 and 3232, respectively. |
| 3234 | BP2 uses the negotiation rules provided by S2 to adjust the bid price by 15%. The bid price changes from $1.40/min to $1.61. |

| | |
|---|---|
| 3242 | AP1 uses the negotiation rules provided by R1 to accept any bid price that is within 20% of the original ask price. Since the original ask price is $2.50/min, any bid price >= $2.00 is acceptable. |
| 3236<br>3244<br>...<br>3238 | Since a new bid specification was calculated in 3234, the process repeats at step 3222 with the new bid price specification.<br>Since a new ask specification was calculated in 3242, the process repeats at step 3222 with the new ask price specification.<br><br>After the 3rd iteration of executing Step 3234, BP2 adjusts the bid price to the maximum of $2.00/min that is acceptable by AP1. All bid specifications are now met. |
| 3246 | The Exchange clears all transactions associated with the request for services. |
| 3250 | The Exchange updates APDB and BPDB, deactivates AP1 and BP2, and notifies the Channel Allocator of results. |

f. Discussion

In an alternative embodiment of the present invention, the present invention can implement the functions of the Exchange 3004 within the Allocator 0044 by utilizing means other than intelligent software agents to enable market-based allocation of underutilized spectrum to service requests.

The present application has described the present inventions in detail with particular reference to preferred embodiments, sequence of steps, and number of steps. However, other embodiments, step sequences, and a larger or smaller number of steps can achieve the same results. Variations and modifications of the present inventions will be obvious to those skilled in the art. The present invention covers all such variations, modifications, and equivalents.

What is claimed is:

1. A system for efficient spectrum utilization comprising:

   a plurality of communications networks, each of said networks including a group of communication stations providing communication services in a corresponding frequency spectrum;

   a plurality of said communications stations operating as service demand entities within each of said networks transmitting requests to operate within an underutilized frequency spectrum available to other communications stations;

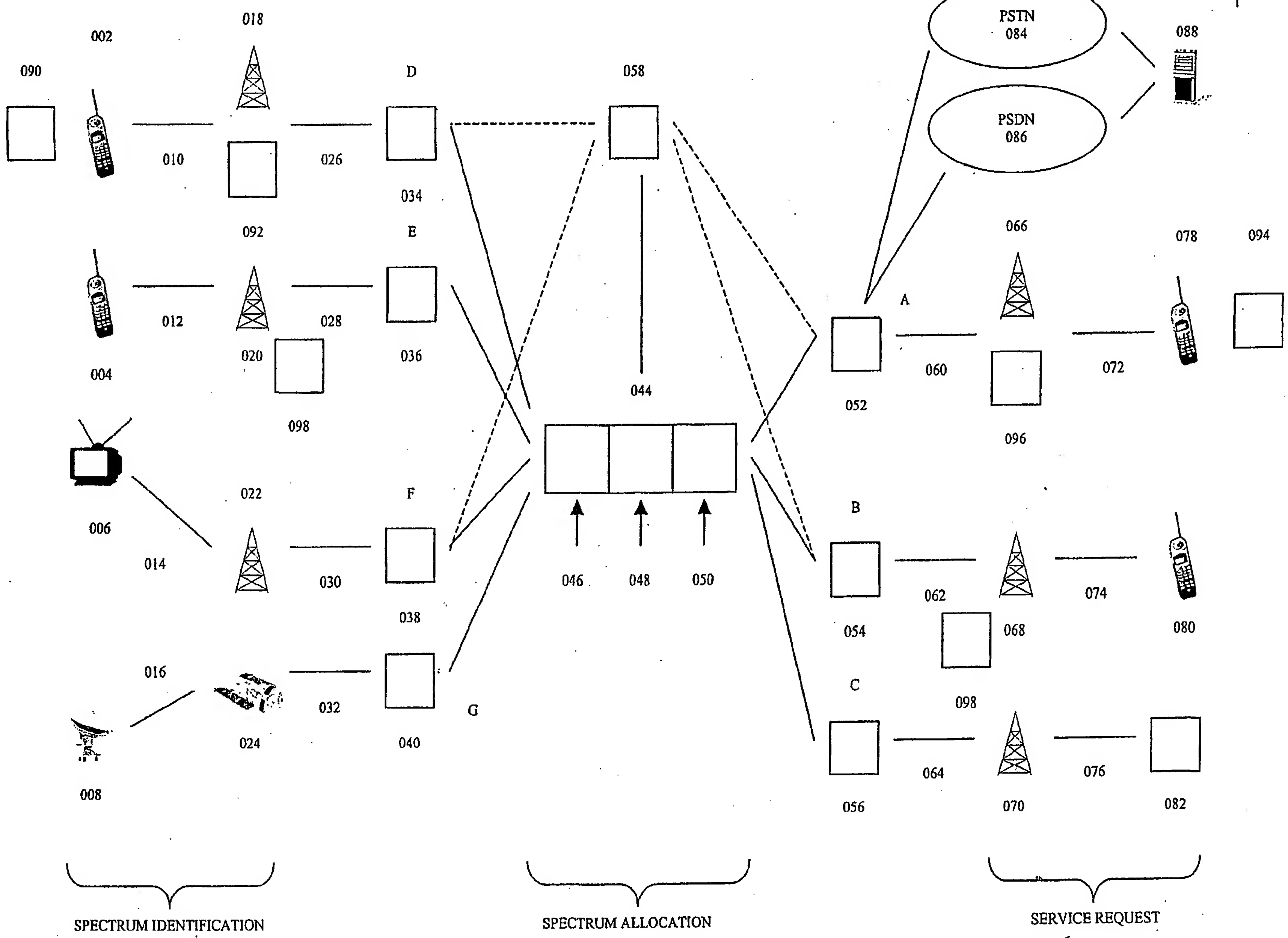
   a plurality of said communication stations operating as service supply entities within each of said networks capable of providing underutilized spectrum available for sharing by at least one of said service demand entities; and

   a spectrum allocator unit configured to receive all requests for spectrum from said service demand entities;

   said spectrum allocator unit also configured to receive all underutilized frequency spectrum available for share by said service demand entities, so that said service demand entities are enabled to provide communication services within said available underutilized spectrum provided by said service supply entities.

2. The system according to claim 1 wherein each of said service demand entities is capable to operate within any of available frequency spectrums utilized by said plurality of communications networks.

FIGURE 1: Reference Model




A B 1 C

FIGURE 2: Method A-2 Flow Chart

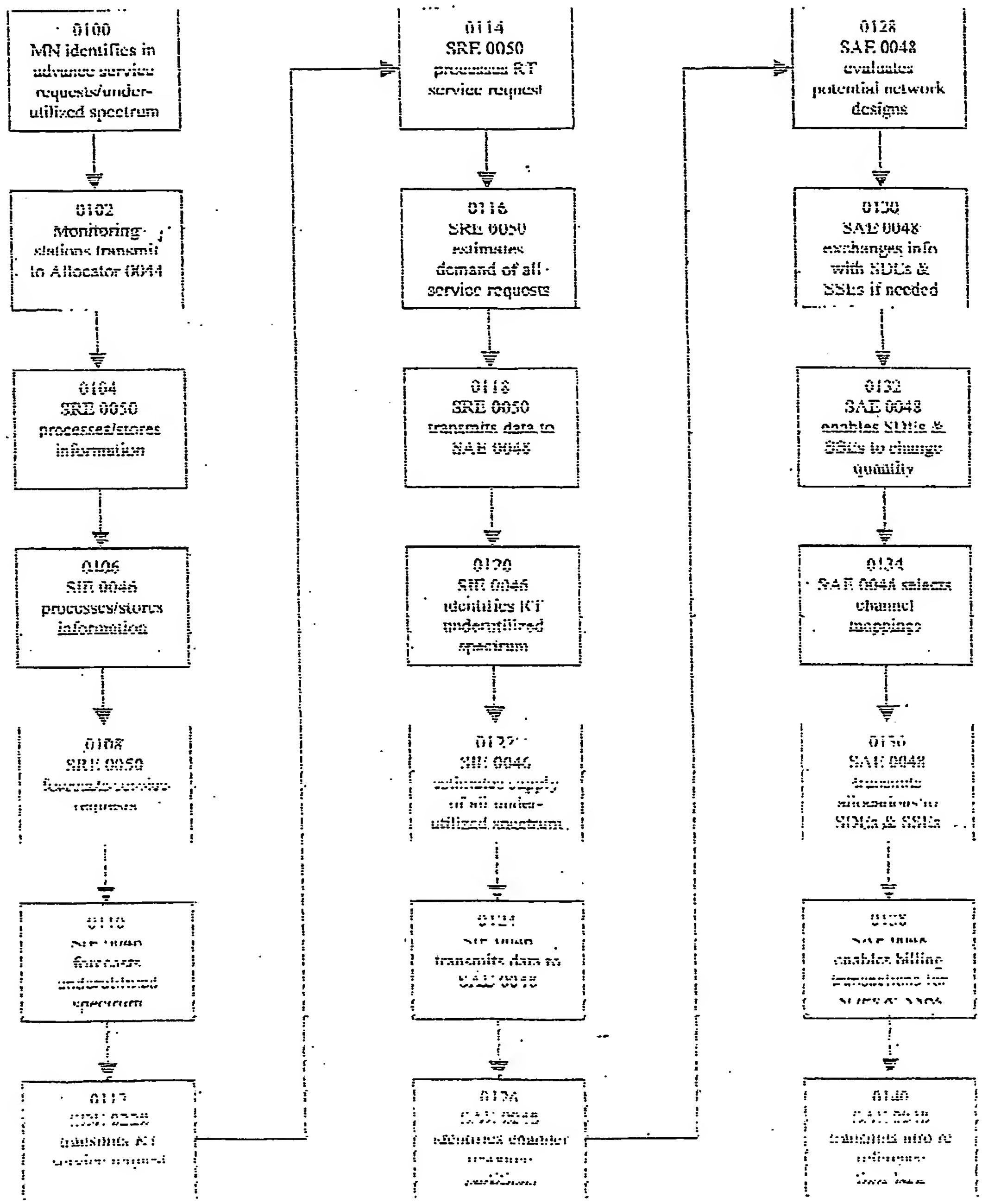


FIGURE 15: Channel Resource Allocator Block Diagram

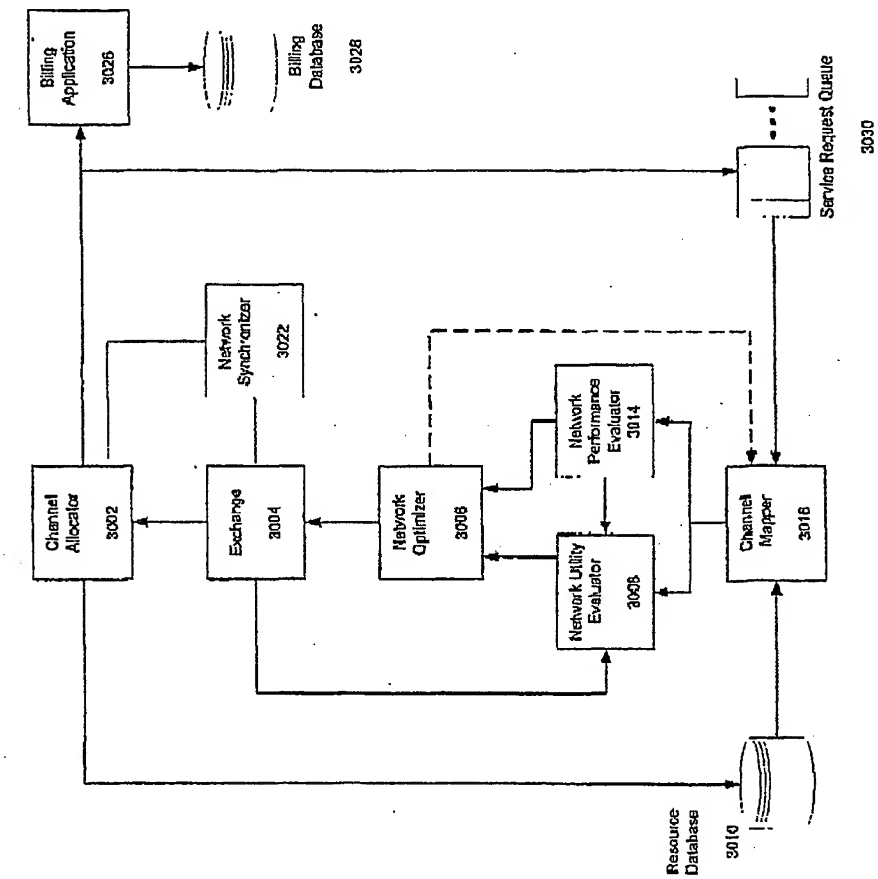
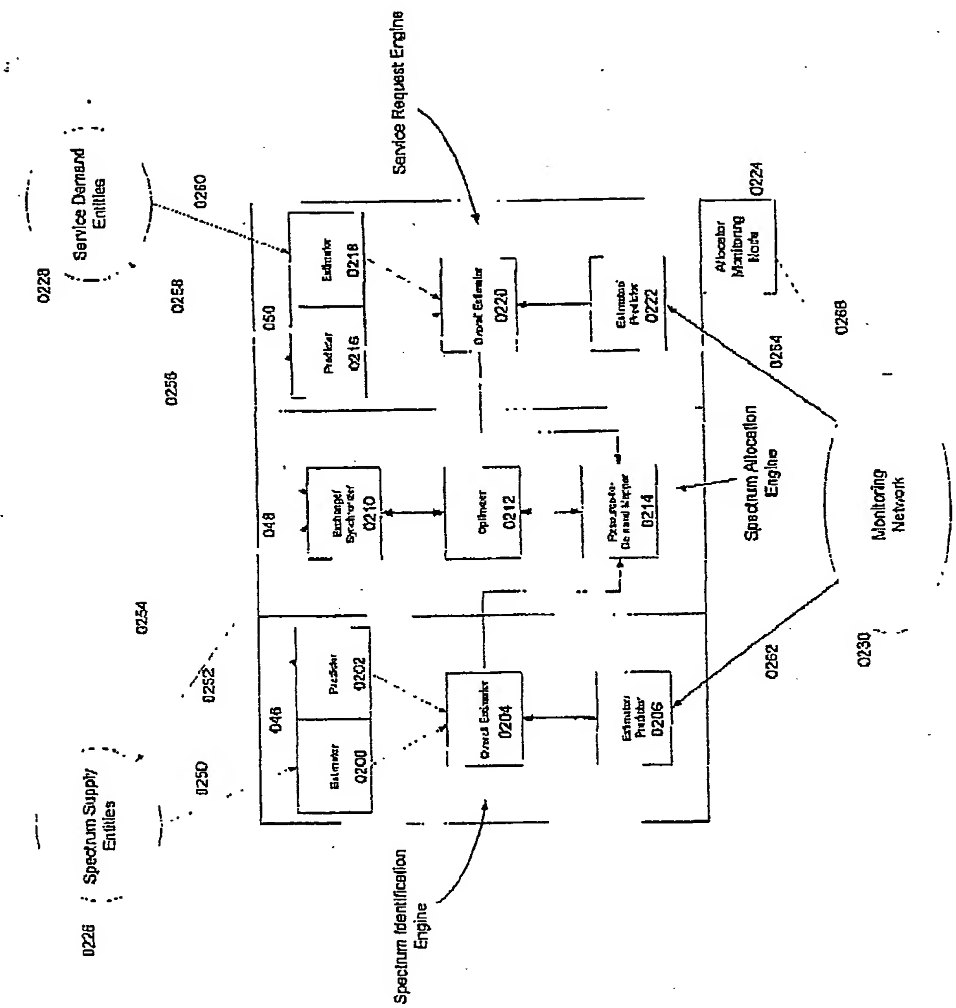


FIGURE 3: Allocator

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# FIGURE 16: Channel Resource Allocation Flowchart

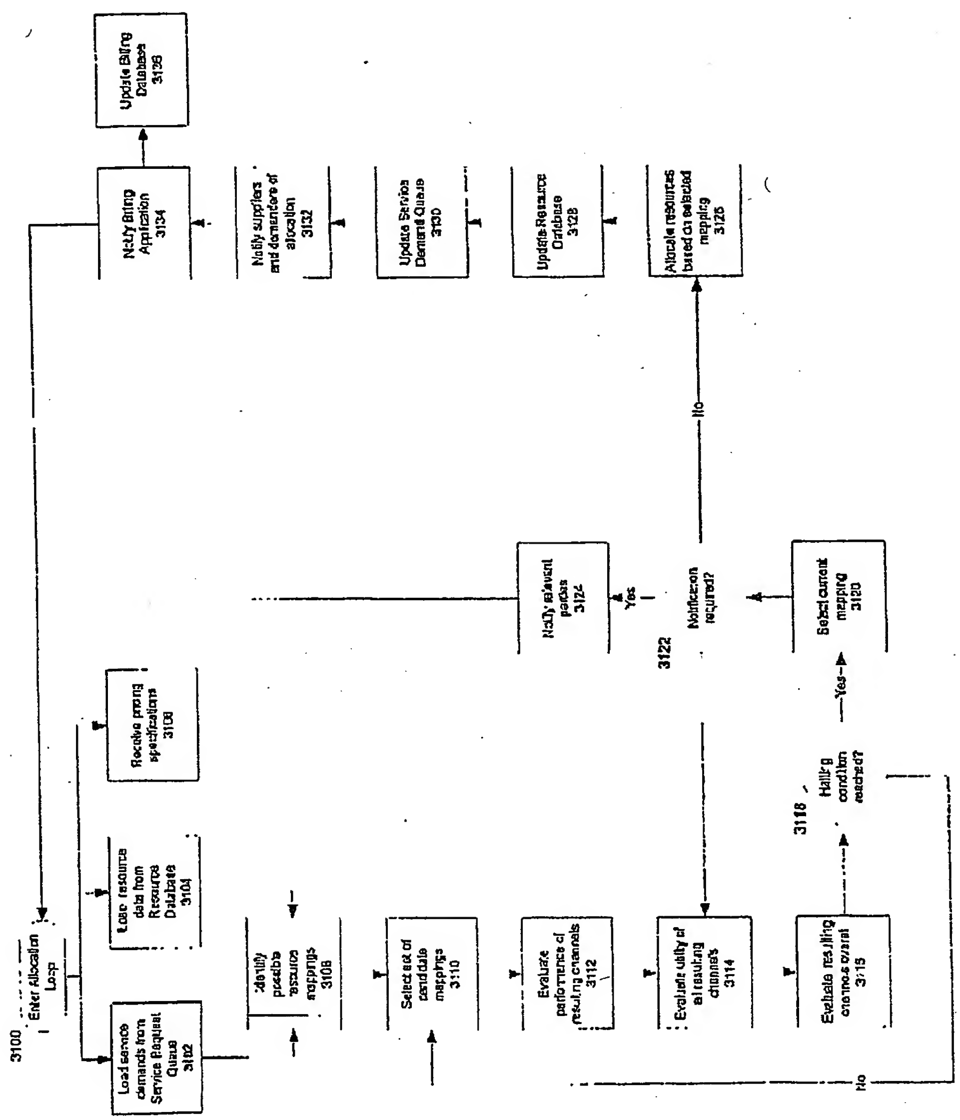

FIGURE 4: Service Request Engine

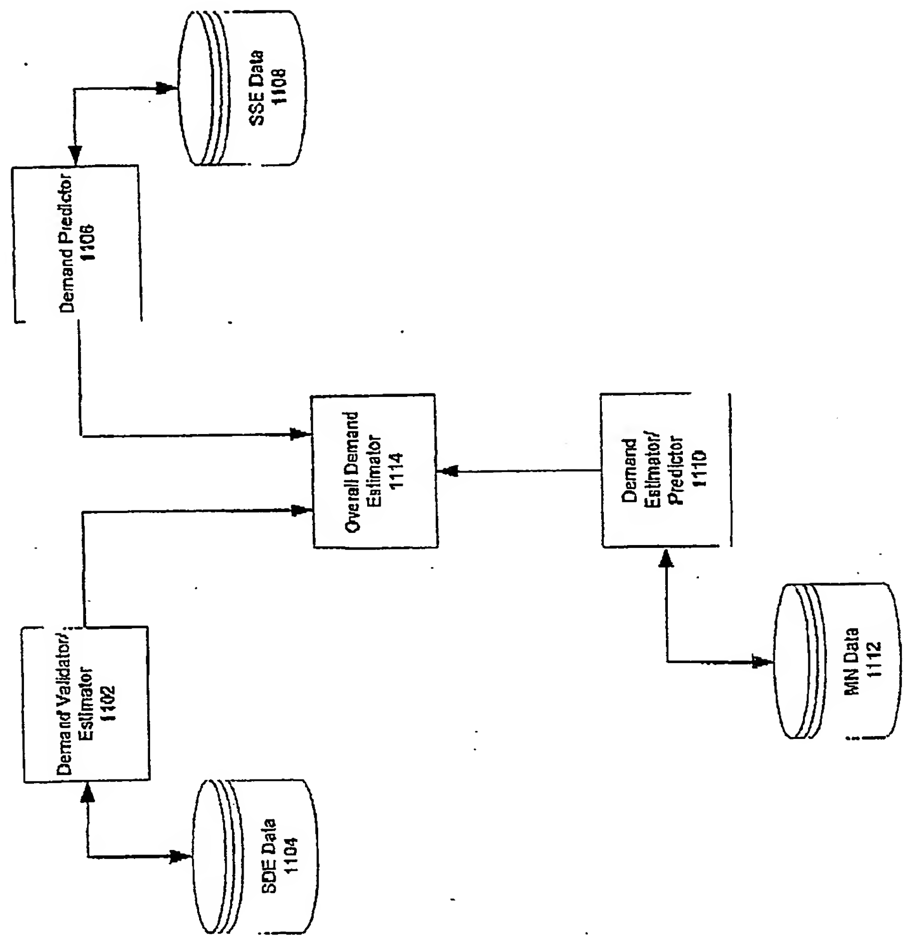


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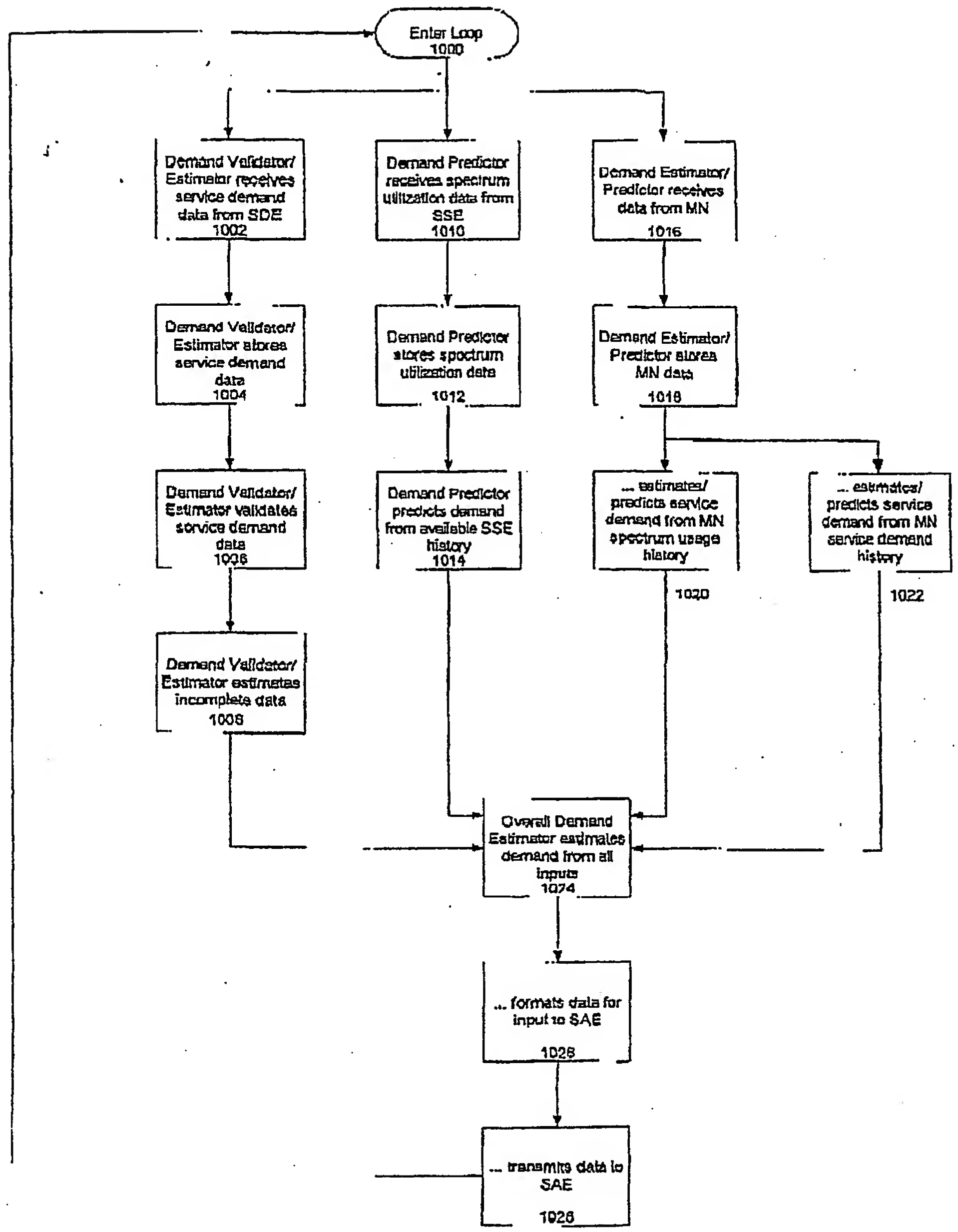
**FIGURE 5: Service Request Engine Flowchart**

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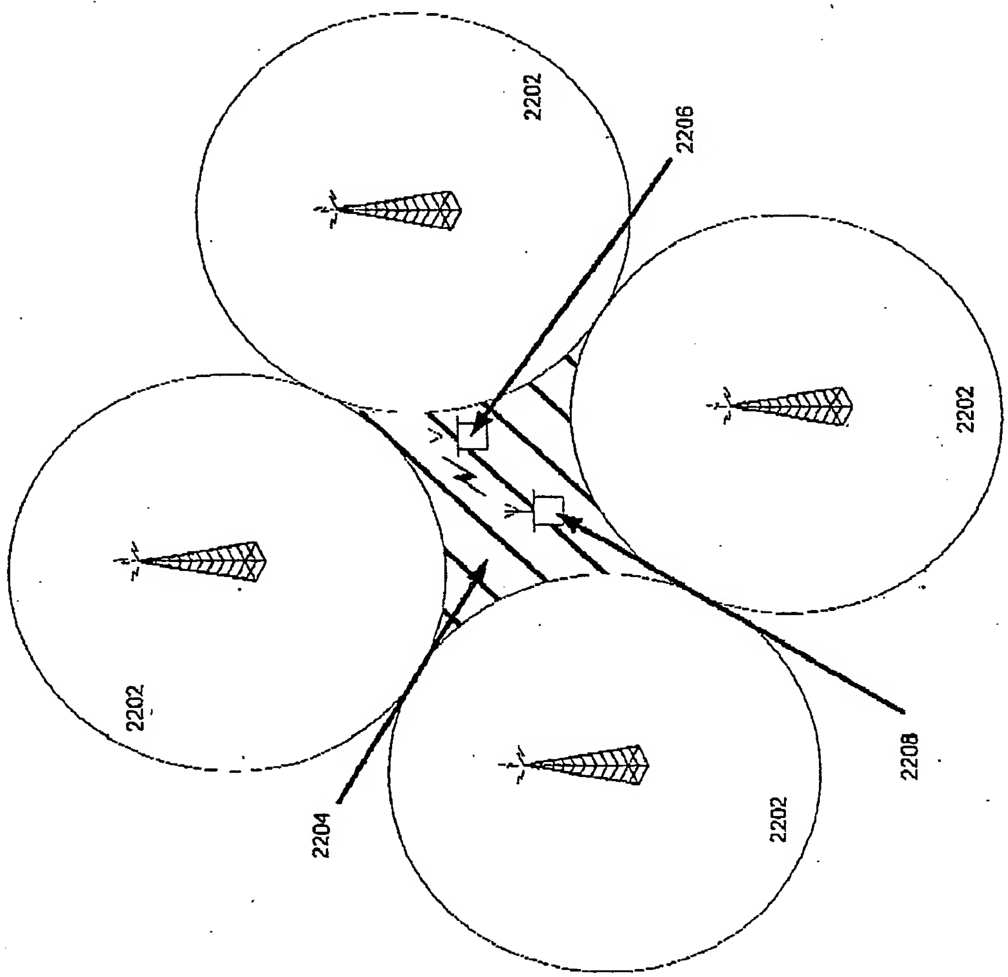


FIGURE 6: Example - Sharing with Incumbent Broadcaster

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FIGURE 7: Spectrum Identification Engine

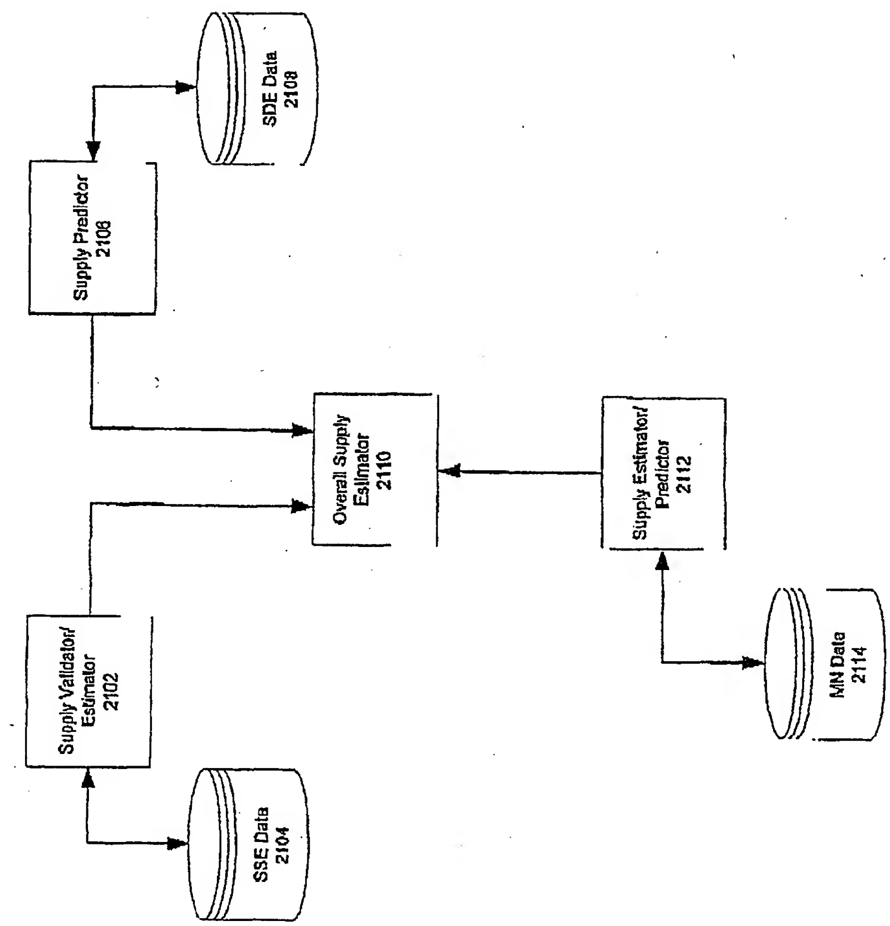

FIGURE 8: Spectrum Identification Engine Flowchart

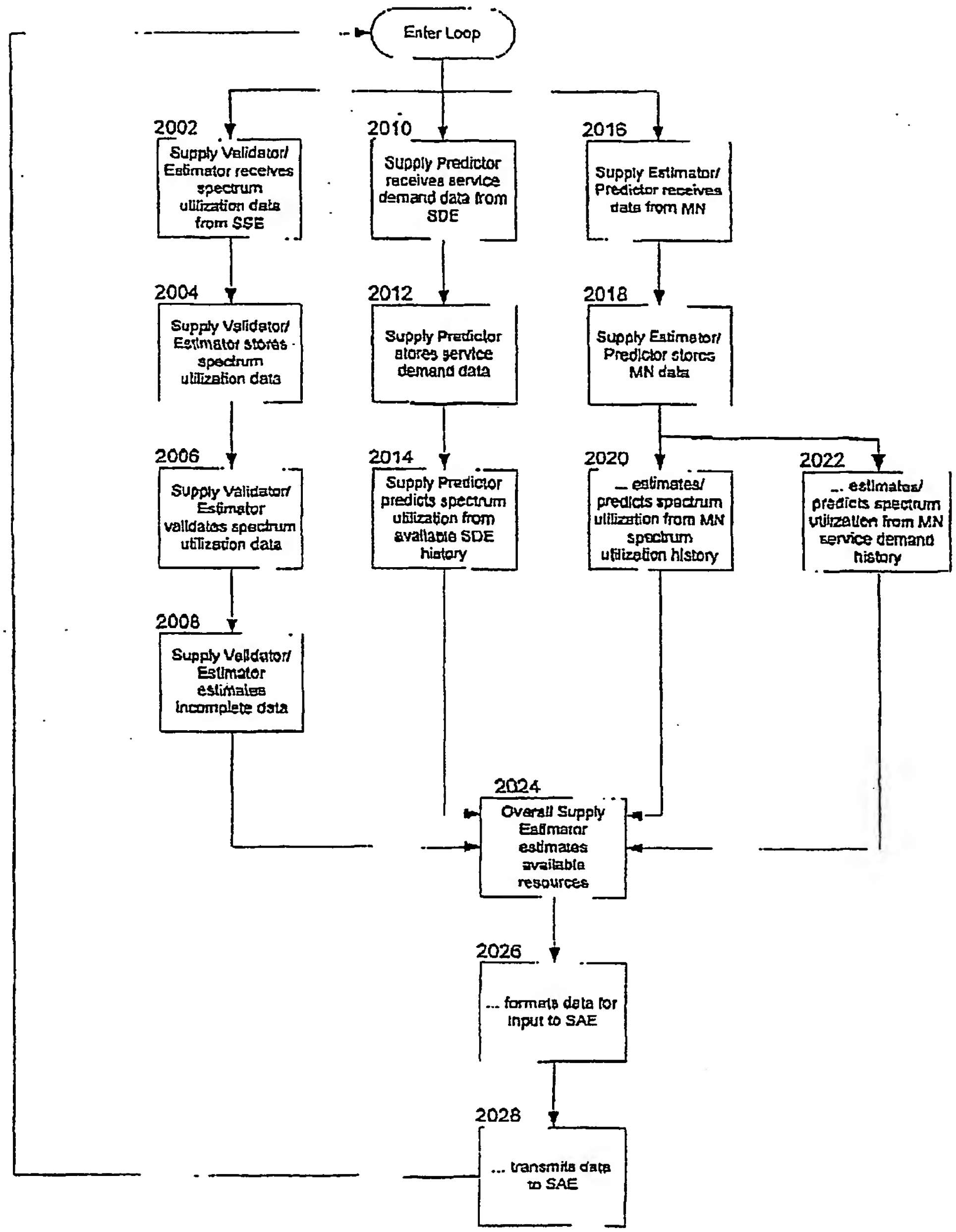


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FIGURE 14: Reference Figure for Example No. 3 (Section D3)

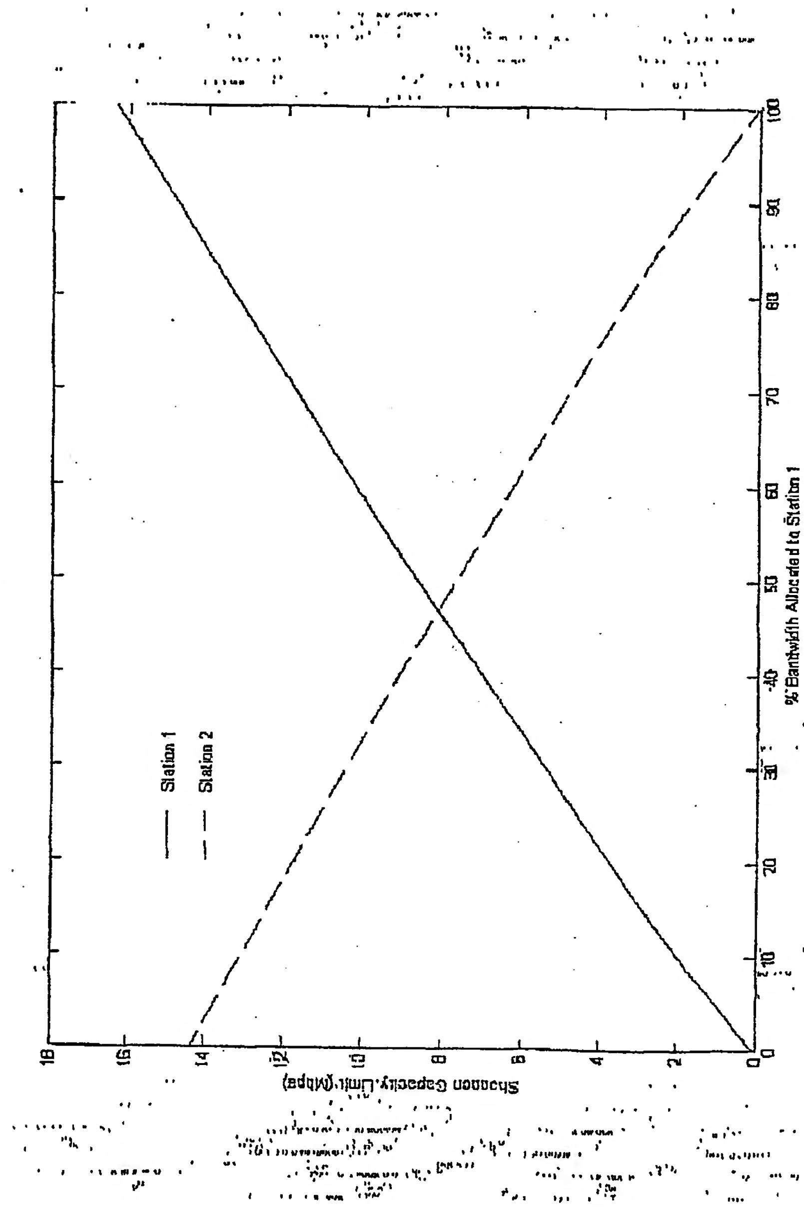

FIGURE 9: Coverage Map (1 of 2)

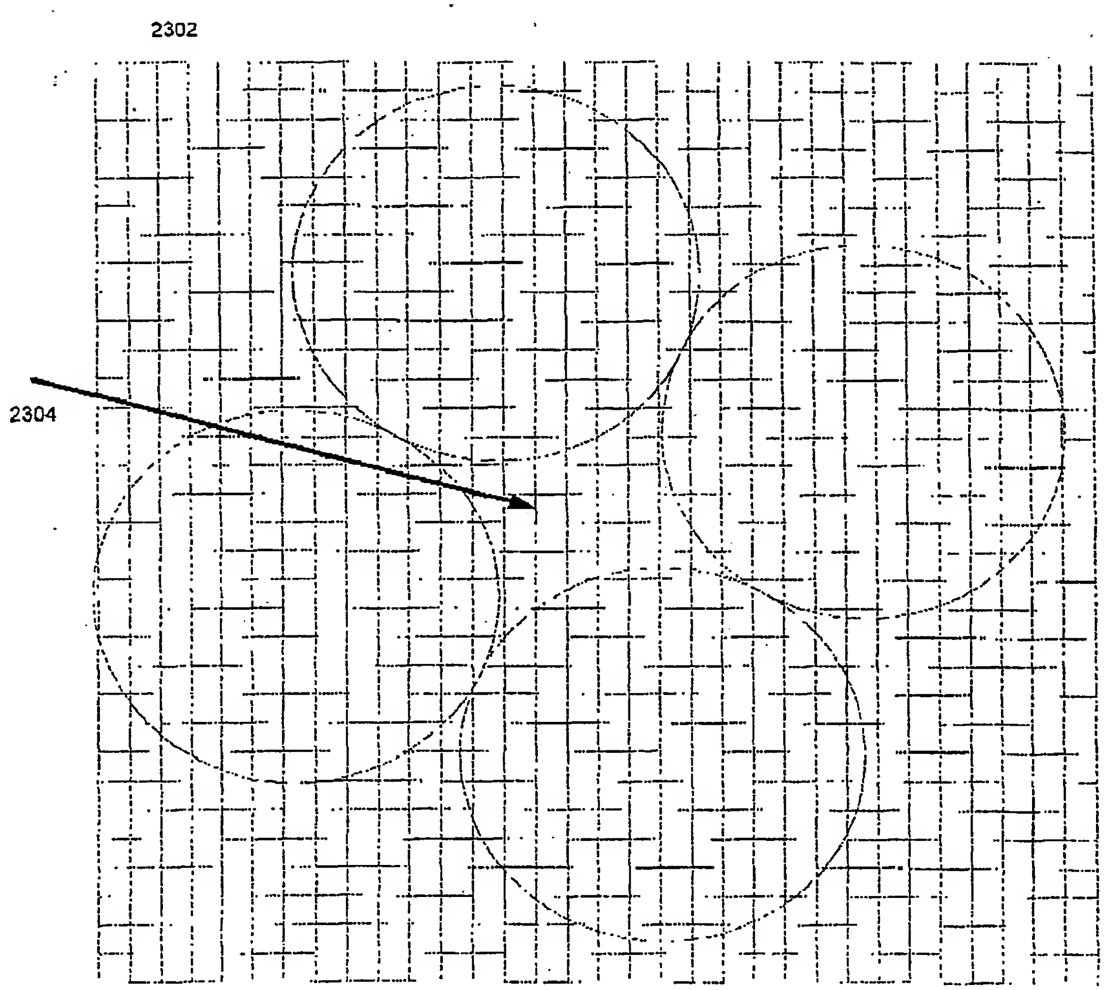


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FIGURE 10: Agent-Based Exchange Block Diagram

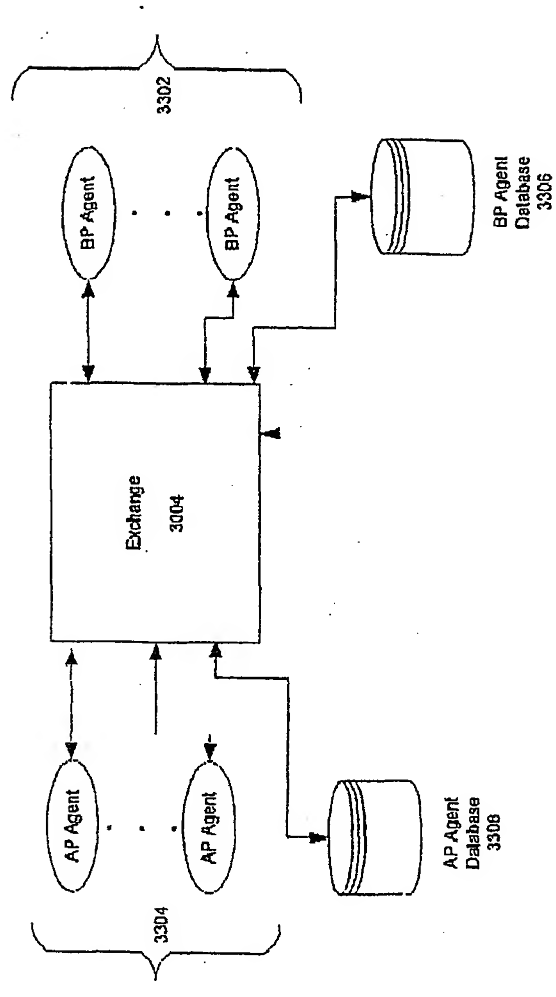

FIGURE 10: Coverage Map (2 of 2)

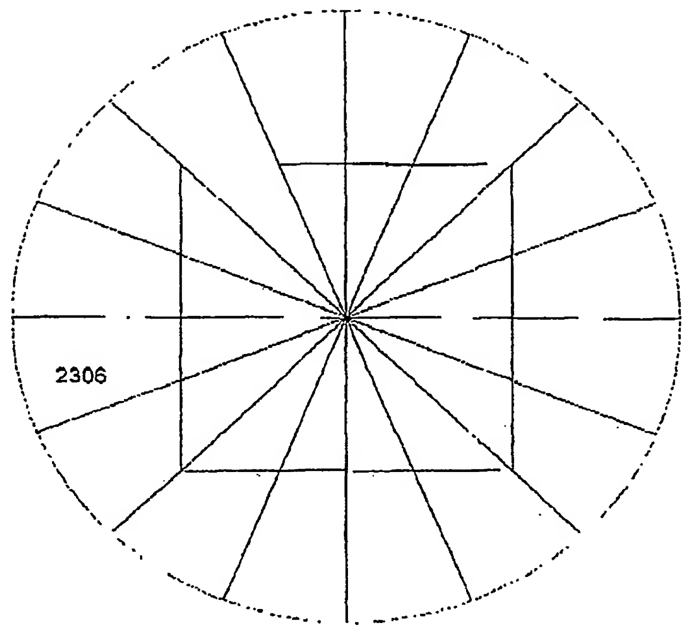


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FIGURE 19: Agent-Based Exchange Flow Chart

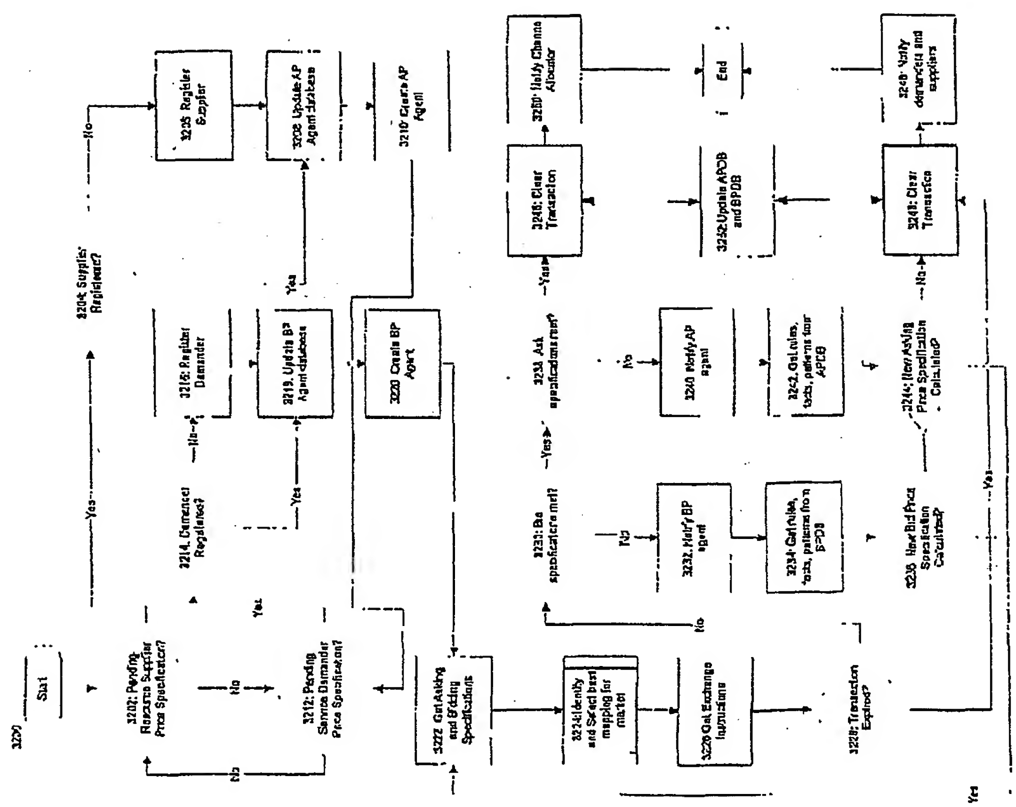

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FIGURE 11: Reference Figure for Method C-2 (1 of 2)

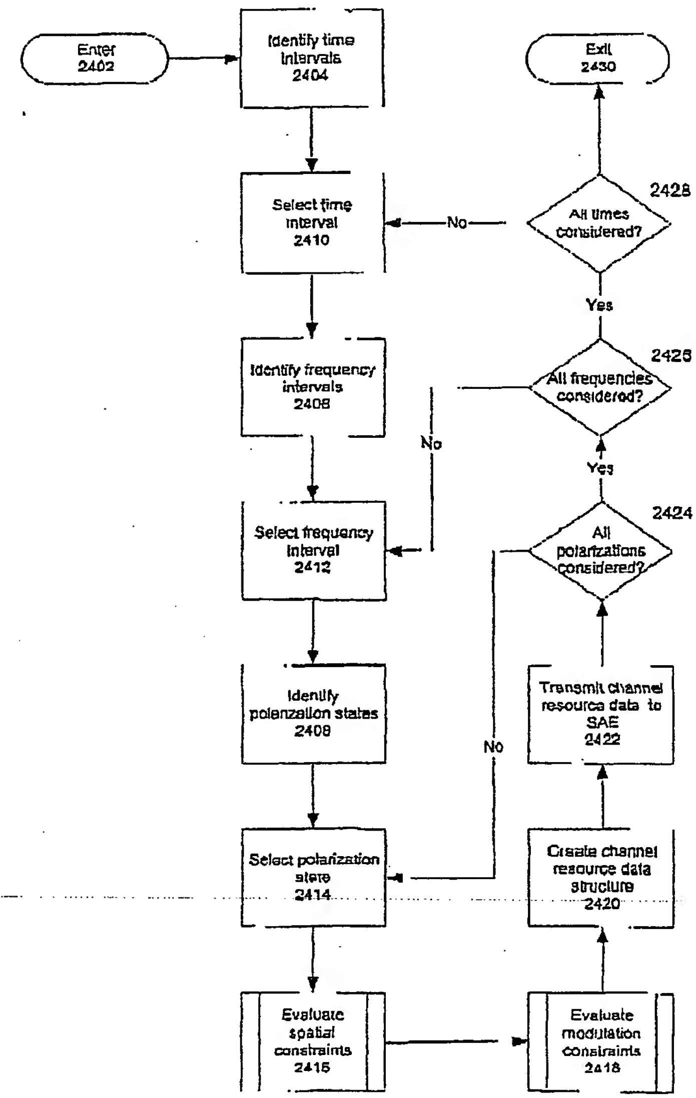


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FIGURE 2E: Spectrum Router Signaling Network (1 of 2)

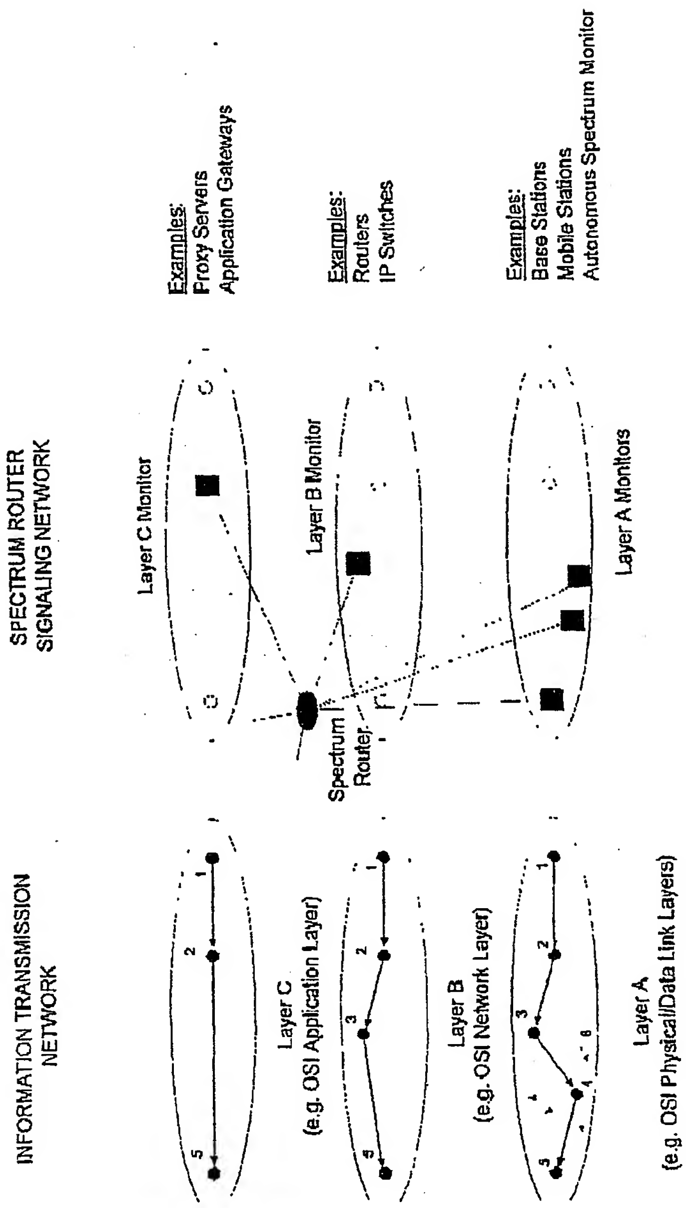


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FIGURE 12: Reference Figure for Method C-2 (2 of 2)

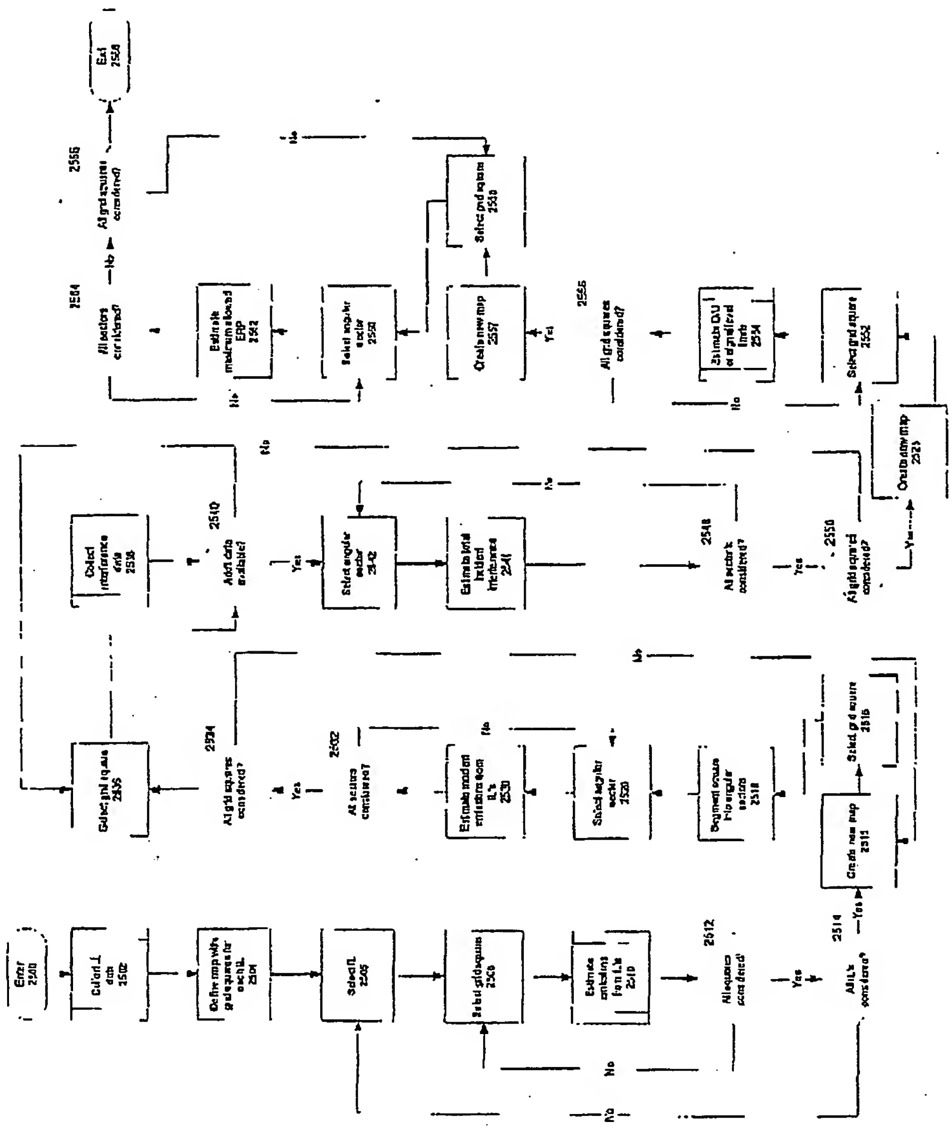

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FIGURE 21: Spectrum Router Signaling Network (2 of 2)

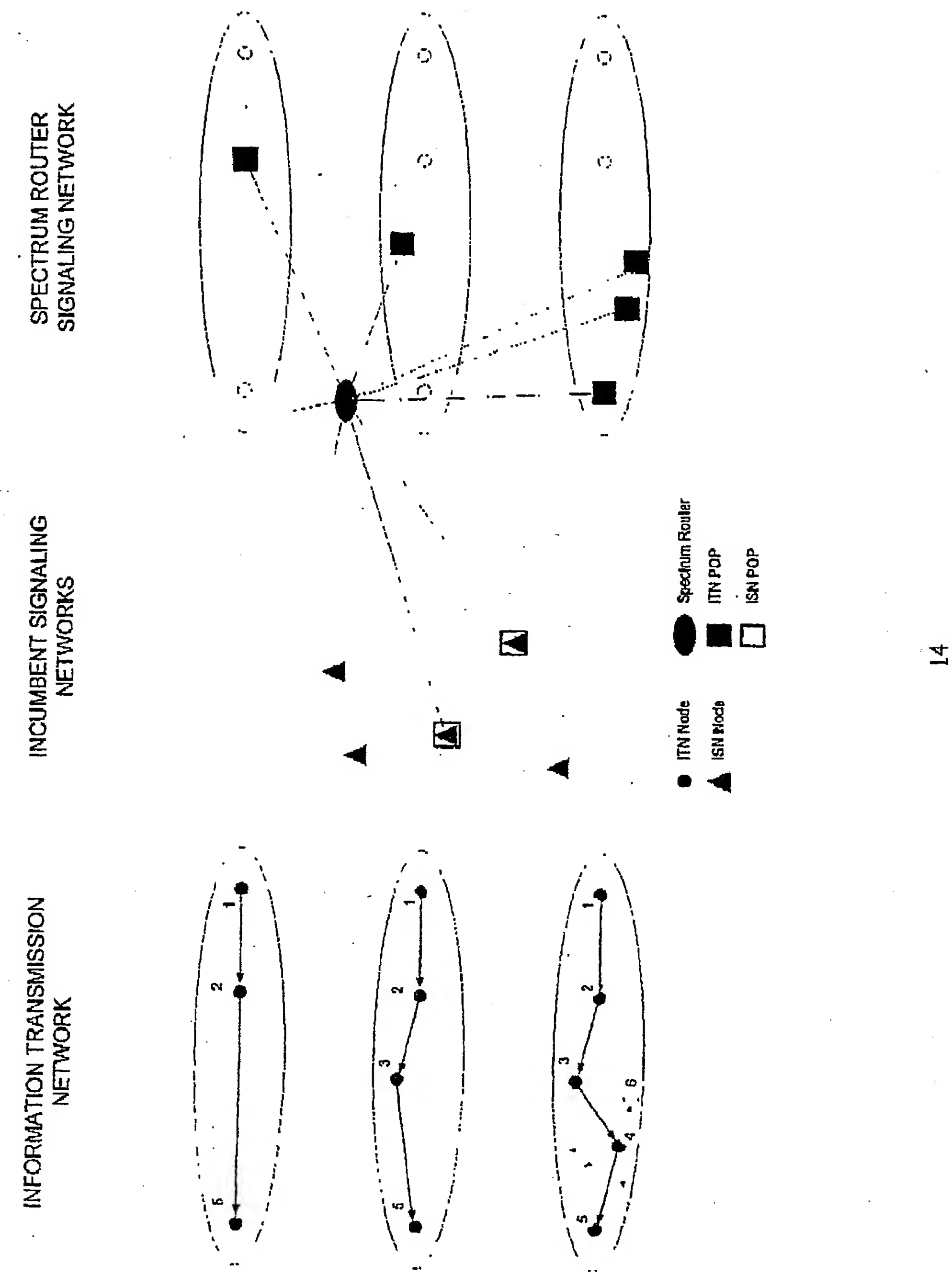

FIGURE 13: Reference Figure for Method C-3

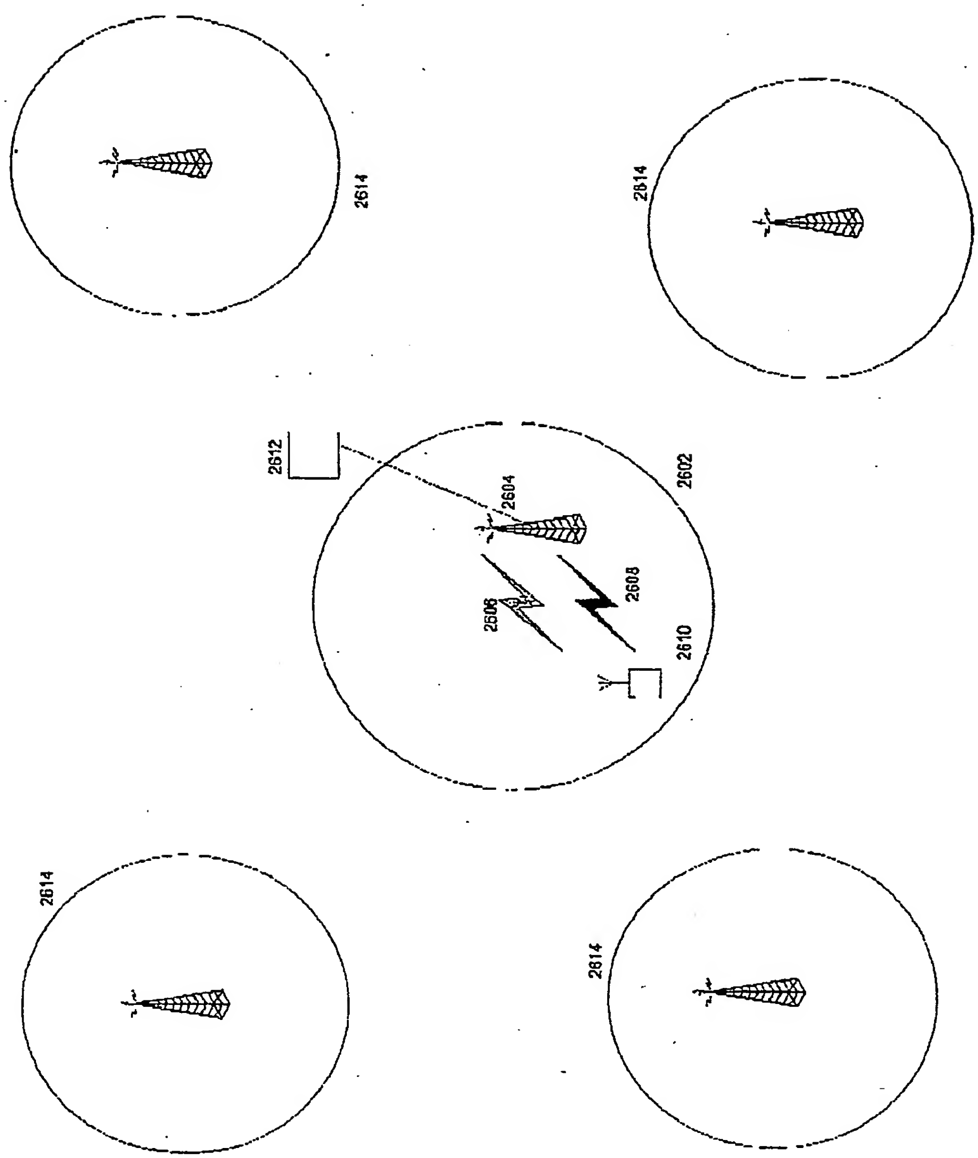


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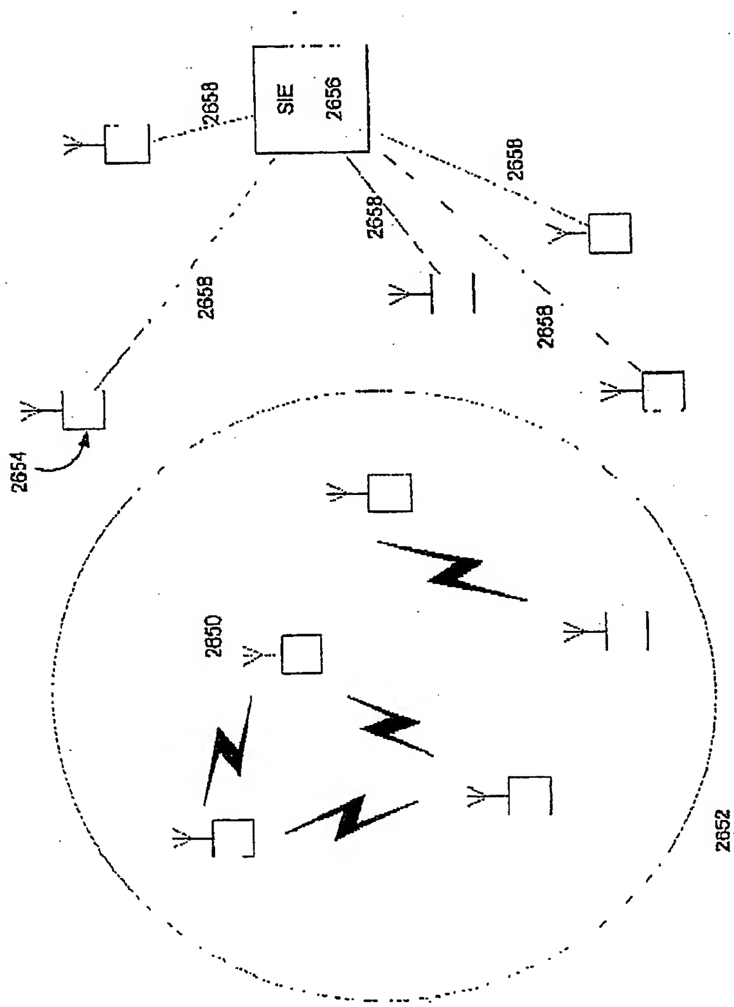
FIGURE 14: Reference Figure for Method C-4

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# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/28768

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) :H04B 7/00
US CL :455/453; 370/466, 467
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/453; 370/466, 467

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | US 5,790,534 A [KOKKO et al] 04 August 1998, col. 1, lines 60-65, col. 6, lines 18-67. | 1-2 |
| Y | US 5,448,621 A [KNUDSEN et al] 05 September 1995, col. 14, lines 15-36. | 1-2 |
| Y | US 6,044,072 A [UEDA et al] 28 March 2000, col. 9, lines 21-67. | 1-2 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 13 DECEMBER 2001 | 28 DEC 2001 |

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| Commissioner of Patents and Trademarks<br>Box PCT<br>Washington, D.C. 20231 | For<br>DANIEL HUNTER |
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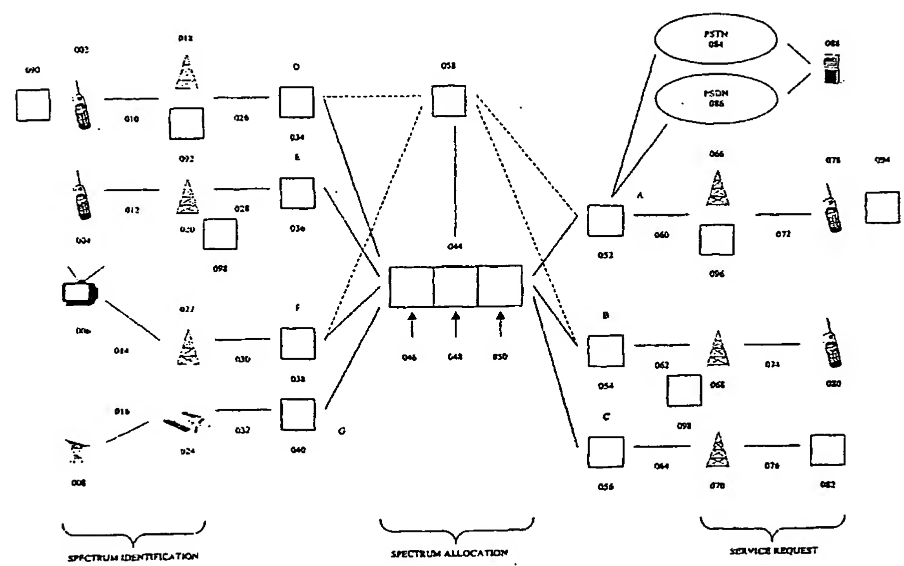
*[Continued on next page]*

(54) Title: SYSTEM AND METHOD AND APPARATUS FOR ENABLING DYNAMIC UTILIZATION OF ALL AVAILABLE SPECTRUM AND DYNAMIC ALLOCATION OF SPECTRUM




(57) Abstract: A system and method for dynamic utilization of all available spectrum (Fig. 1) obtains service requests from communication stations such as a wireless unit (004). The system takes the request in a real time, and in advance, identifies underutilized spectrum to match the uderutilized spectrum to the service request. In addition the system is a signaling system that interconnects different wireless networks to enable them to exchange information.

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